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GEOLOGY AND ORE-DEPOSITS OF THE GOLDFIELD DISTRICT, NEVADA.[1]

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PART I—GEOLOGY.

SITUATION AND TOPOGRAPHY.

The Goldfield district, of which the geographic position is shown in Fig. 26, may be briefly characterized as part of a hilly plateau ranging from 5,400 to 6,600 feet in elevation, and diversified by many irregularly distributed peaks and knobs. Much of the surface consists of gentle slopes covered with the usual detritus of arid regions and there is a considerable expanse of lava-capped mesa southwest of the town of Goldfield. Rough masses of silicified rock, which, owing to their hardness, have resisted erosion and jut out in bold relief, are a characteristic feature of the landscape.

GENERAL GEOLOGY.

The geologic structure is essentially that of a low, domical uplift of Tertiary lavas and lake sediments resting upon a foundation of ancient granitic and metamorphic rocks. The erosion of this flat dome has exposed the pre-Tertiary rocks in the cen-

[1] Published with permission of Director of U. S. Geological Survey.

The Goldfield district has been fully described in Professional Paper No. 66 of the U. S. Geol. Survey. The present paper is an attempt to present the salient results of that investigation in as concise a form as is possible and was prepared at the suggestion of the editor. The reader desiring fuller information regarding any phase of the subjects here briefly treated is urged to consult the original report, from which also most of the illustrations here used were taken.—F.L.R.

tral part of the district, and these outcrops are surrounded by wide concentric zones of successively younger formations. (See Plate I.) Some of the later lavas were erupted after the dome had been elevated and truncated.

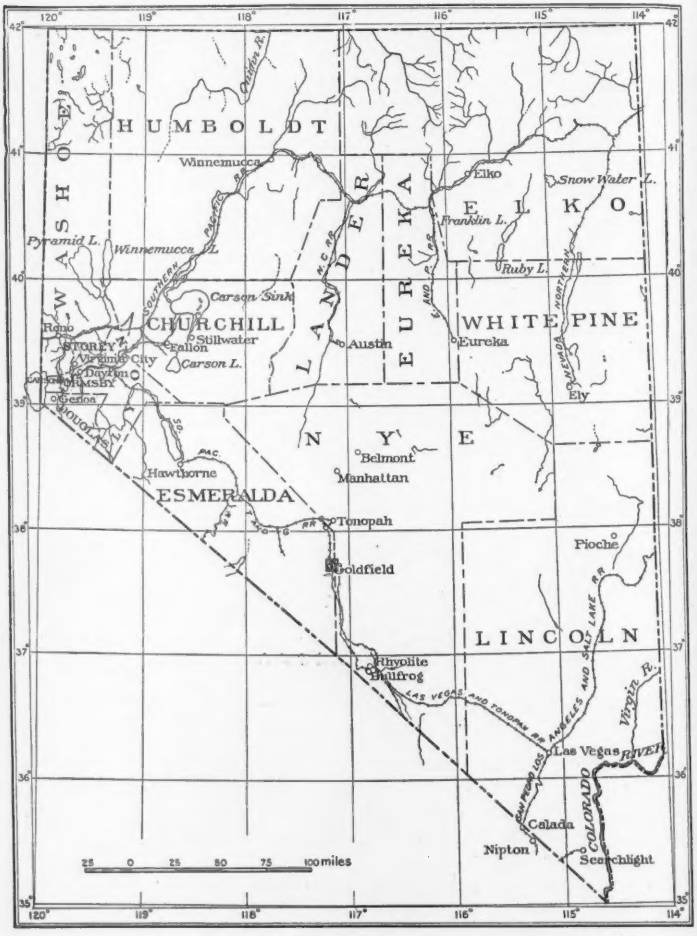

FIG. 26. Index map showing position of the Goldfield district.

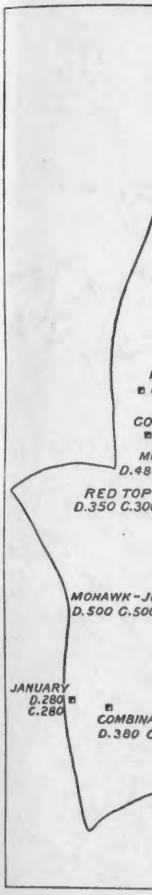

FIG. 27. Plan of
feet

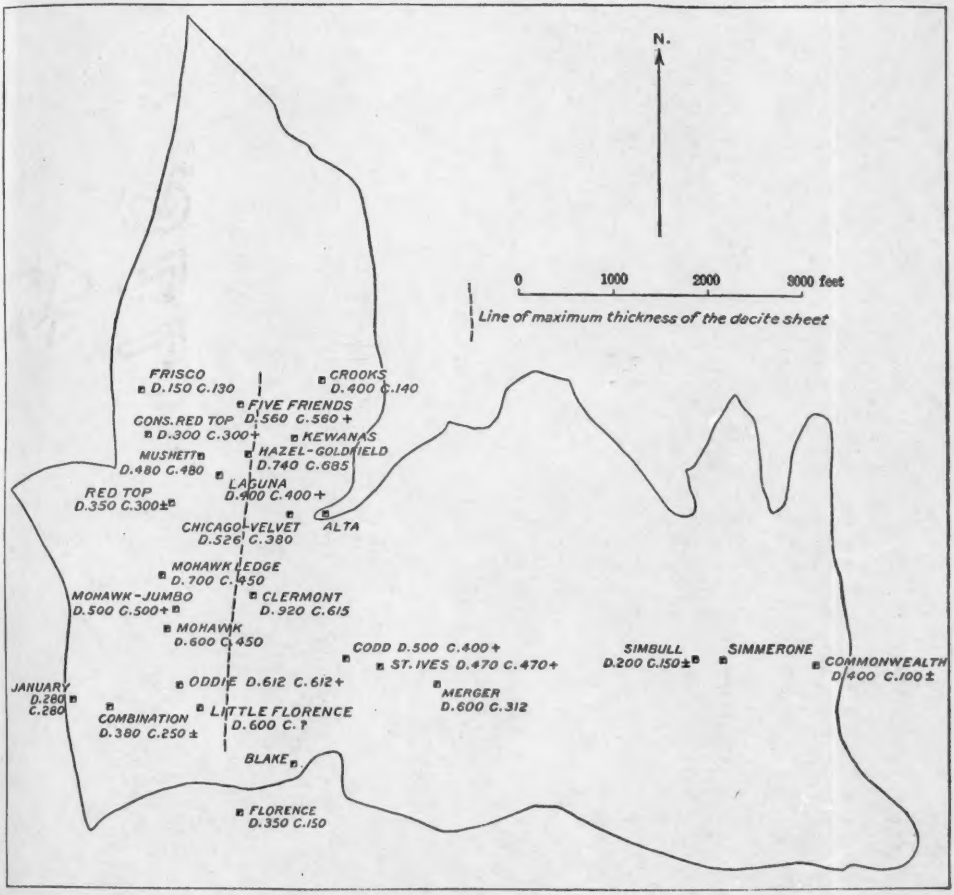

FIG. 27. Plan of the dacite mass near Goldfield, showing positions of shafts that penetrate it, their depths in feet in 1908 (*D*), and the depths (*C*) at which they go into the underlying rocks.

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The oldest rocks exposed are found on Columbia and Vindicator mountains. Originally thin-bedded limestones or calcareous shales, with subordinate beds of sandstone, this formation is now much contorted and metamorphosed. The calcareous beds have been changed to compact aggregates of quartz (jasperoid), and the sandstone to hard, vitreous quartzite. These beds are probably Cambrian. The metamorphism is due to the intrusion into these sediments of masses of alaskite, a granitic rock composed essentially of quartz and orthoclase. Most of the alaskite contains a very little black mica with some plagioclase and northeast of the summit of Vindicator Mountain the alaskite mass grades into a biotite granite. The alaskite was probably intruded at about the close of Jurassic time. This event was followed by a long interval during which the region was eroded to the surface of moderate relief subsequently covered by the Tertiary lavas.

The sequence of Tertiary eruptions as exemplified by the rocks of the Goldfield district is given in the following list, the oldest rocks being at the bottom. To avoid confusion between rocks of like petrographic character erupted at different periods, recurrent kinds are distinguished by local geographic terms derived from places at or near which the corresponding rocks may be seen. A few dikes of uncertain position in the sequence are not included in the list.

The Vindicator rhyolite rests on Cambrian sediments and alaskite on the flanks of Vindicator Mountain and on the summit of Columbia Mountain. Much of it is greatly altered and contains abundant alunite.

The latite occupies an area a little over two miles in diameter in the center of the district, and a smaller area south of Columbia. The rock, nowhere fresh, is normally dull purplish or greenish gray. A spotted or mottled appearance, due to flow brecciation, is rather characteristic. The freshest obtainable specimens of the latite show phenocrysts of feldspar, hornblende and mica in a compact, streaky groundmass that was evidently once a glass with well-marked flowage lines. As a rule, the latite, when it has not been subjected to the intense local alteration connected with

SEQUENCE OF THE TERTIARY ERUPTIONS.

Formation or map name.	Petrographic name.	Occurrence.
Malpais basalt ...	Dolerite	Flow or flows, with a few small intrusions.
Rabbit Spring formation	Breccia, conglomerate, and sandstone	A variable and for the most part thin deposit; probably fluviatile.
Spearhead rhyolite	Rhyolite	Flow or flows.
Pozo formation..	Conglomerate ...	Fluviatile deposit. Conformably underlies Spearhead rhyolite and unconformably overlies the Siebert formation.
Siebert formation	Conglomerate, sandstone, tuffs, and diatomaceous earth.	Lake beds.
Mira basalt	Quartz-bearing doleritic basalt.	Flow intercalated in Siebert formation.
Siebert formation	Conglomerate, sandstone, tuffs, etc.	Lake beds.
Espina breccia....	Dacitic breccia ..	Roughly bedded deposit.
Andesite breccia..	Andesite breccia..	Roughly bedded pyroclastic deposit.
Meda rhyolite....	Rhyolite	Flow.
Dacite vitrophyre	Dacite vitrophyre.	Flow.
Chispa andesite..	Andesite	One or more flows in the dacite vitrophyre.
Dacite vitrophyre	Dacite vitrophyre.	Flows.
Dacite	Dacite	Sheet-like and irregular intrusive masses passing into flows and breccias east of the area mapped.
Milltown andesite	Andesite	Mainly flows, but with some dikes and intrusive masses and with some tuff and breccia. Locally includes some effusive basaltic rocks which are not exposed at the surface.
Morena rhyolite..	Rhyolite	Intrusive masses.
Sandstorm rhyolite	Rhyolite	Flows.
Kendall tuff.....	Rhyolitic and andesitic tuff	Obscurely bedded and in part lenticular deposits closely associated with the Sandstorm rhyolite.
Latite	Latite	Flow.
Vindicator rhyolite	Rhyolite	Flow.

ore deposition, may be distinguished from the later andesitic rocks by the absence of fresh phenocrysts and the peculiar streakiness of its groundmass, which resembles the groundmass of a rhyolite rather than that of most andesites. The rock is a flow resting generally upon a clean and rather uneven surface of alaskite and Paleozoic sediments, although on Vindicator Mountain it lies in part on the oldest rhyolite. Its maximum thickness is tentatively estimated at 300 feet; it may be considerably more.

Overlying the latite, or resting on the pre-Tertiary rocks where the latite is absent, is a series of thin, glassy rhyolite flows which is best developed in the rounded white hills northwest of Columbia Mountain. This, the Sandstorm rhyolite, is closely associated with pale greenish tuffs (Kendall tuff) of mingled latitic and rhyolitic character and is cut by masses of intrusive Morena rhyolite. The effusive rhyolite is usually nearly white, has conspicuous flow lamination, and weathers in thin, shelly flakes. Certain varieties or portions of this rhyolite, when weathered, have a deceptive resemblance to indurated clay shale. The rhyolite appears to have been thickest in the vicinity of Columbia Mountain and to thin out to the southeast.

After the eruptions of the earlier rhyolites the region was covered with successive flows of andesite, accompanied by subordinate layers of andesitic tuff. The products of these eruptions, the Milltown andesite, constitute the most extensive formation in the district. The total thickness of this deposit, as of most of the other volcanic formations in this district, can not be determined, owing to the slight deformation of the rocks, their poor exposures, the comparatively slight topographic relief, and the absence of persistent datum planes, such as may usually be found in stratified rocks. It probably lies between 600 and 800 feet.

The dacite, whose eruption followed the andesitic period, is in many respects the most interesting rock in the district and is very important from an economic point of view. It occupies a considerable area east of Goldfield and Columbia and is the principal country rock of the upper workings of the larger mines.

This mass appears to be an intrusive sheet about 700 feet in maximum thickness, but in most places is much thinner. Its general outline is shown in Fig. 27. A larger body of dacite extends southward from Tognoni Springs and forms some of the high hills just east of the portion of the district particularly studied. This body makes up a large part of Preble Mountain, where it is probably intrusive into the Milltown andesite. East of the area investigated, however, the dacite is undoubtedly effusive and is associated with the volcanic breccia. Smaller masses of dacite occur elsewhere in the district. Mineralogically and chemically the dacite at Goldfield is merely a quartz-bearing andesite and is in no way similar to the more siliceous rocks called dacite by Spurr in his report on the Tonopah district.

Contemporaneously with, or shortly after, the dacite intrusion a rock classed as dacite vitrophyre was erupted as a series of flows and is now extensively exposed in the low hills in the southeast corner of the district. The dacite vitrophyre is associated with one or more intercalated flows of andesite (Chispa andesite). The eruption of the dacite vitrophyre was followed by a flow of rhyolite (Meda rhyolite) and by eruptions of andesitic breccia.

After these eruptions the region was covered by an extensive body of fresh water in which were laid down 1,000 feet or more of bedded conglomerates, tuffs, tuffaceous sands, pumiceous ash, and diatomaceous earth. These deposits, the Siebert formation, cover a large part of the district, particularly in its outskirts. They underlie the town of Goldfield and stretch both northward and southward beyond the limits of the area studied. They also extend beneath Malpais Mesa southwest of town and are well exposed in the steep bluffs of Pozo Canyon, where the beds dip generally westward at angles ranging from 25° to 30°. Volcanism continued active during the existence of the lake, as is shown by the prevailingly volcanic nature of the sediments and the occurrence within them of a thick flow of quartz-bearing basalt (Mira basalt) and thin flows of glassy rhyolite.

In the eastern part of the district, northeast of Preble Mountain, are some bedded breccias and tuffs from 200 to 300 feet

in present thickness. They rest upon dacite and andesite and are made up largely of fragments of these rocks, particularly of dacite mingled with abundant fragments of volcanic glass and some sandy tuffs. These beds, the Espina breccia, are possibly of the same age as the lake beds just described.

The dacite vitrophyre is cut by dikes of andesite. Whether these were erupted before, during, or after the lacustrine episode is not determinable.

Lacustrine conditions were ended by uplift of the region, the domical structure being then initiated. After the lake beds had been beveled by erosion and entirely swept away from the central part of the district eruptions of rhyolite lavas again began.

The latest rhyolite, called the Spearhead rhyolite, is a light-pink or pale-green rock, rather porous and containing abundant pumiceous fragments. It comprises two flows about 100 feet in total maximum thickness, which are exposed in the bluffs southwest of Goldfield. The rhyolite is in some places overlain by a few feet of unconsolidated tuffaceous sand and volcanic gravel, called the Rabbit Spring formation.

Finally, the volcanic history of the region was brought to a close by the eruption of one or more flows of olivine basalt. This is the dark rock that is conspicuous as the capping of Malpais Mesa southwest of town, and has accordingly been given the local designation of the Malpais basalt. It also forms the summits of Myers and Blackcap mountains, and of several hills south and east of the area, especially studied. The larger areas of this rock represent remnants of flows which rest upon a nearly horizontal surface of older rocks; but some smaller masses, such as that shown on the east slope of Vindicator Mountain, are intrusive and may fill orifices through which the basalt reached the surface to spread out as flows. The eruption of the Malpais basalt was followed by a period of erosion which, varied by slight deformations of the rocks, has continued to the present.

There is no paleontological evidence upon which to assign the Tertiary formations at Goldfield to the recognized series of that system. The prelacustrine volcanic rocks are provisionally

regarded as Eocene, the lacustrine formations as Miocene, and the postlacustrine formations as Pliocene.

A generalized columnar section of the rocks of the Goldfield district is shown in Fig. 28, and in the following table are assembled chemical analyses of some of the principal igneous rocks.

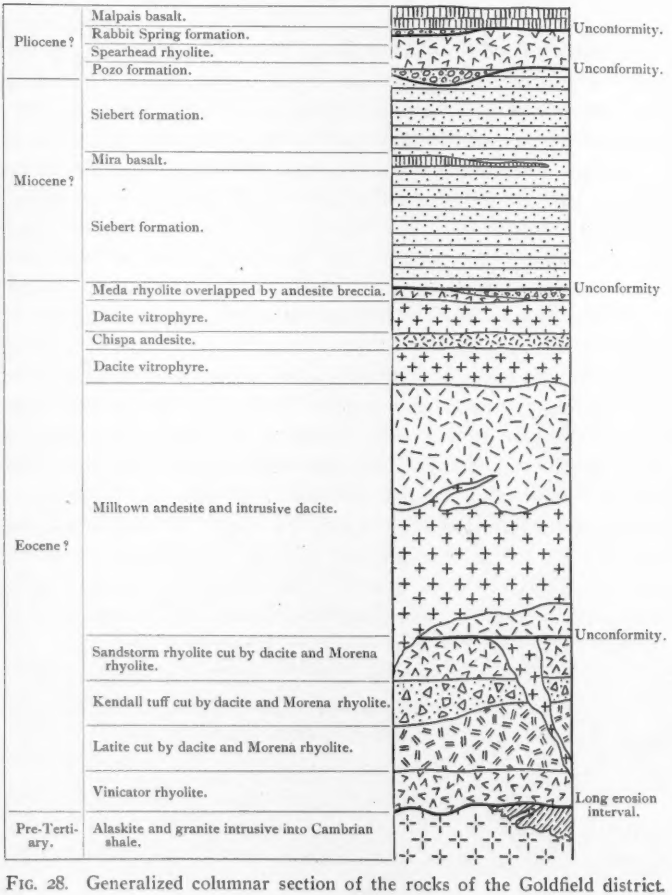


FIG. 28. Generalized columnar section of the rocks of the Goldfield district.

CHEMICAL ANALYSIS OF IGNEOUS ROCKS OF THE GOLDFIELD DISTRICT.

	Latite.	Milltown Andesite.				Dacite.	Dacite vitrophyre.	Malpais Basalt.		
	1	2	3	4	5	6	7	8	9	10
SiO_2	61.14	58.06	60.41	54.66	63.16	59.95	61.25	55.99	48.20	48.59
Al_2O_3		17.13	16.59	17.53	16.74	15.77	15.92	16.14	21.47	17.80
Fe_2O_3		3.83	3.18	3.18	3.94	3.34	3.75	4.42	5.89	8.70
FeO		1.91	1.70	3.52	0.47	2.34	1.17	.13	2.20	0.93
MgO		2.60	2.13	3.62	1.12	2.73	2.28	1.51	3.33	4.85
CaO	5.60	6.33	5.26	7.33	4.07	5.84	5.39	4.17	10.60	10.49
Na_2O	3.26	3.34	3.94	3.56	3.88	3.07	3.19	3.04	3.10	3.06
K_2O	3.90	2.61	1.70	2.22	3.71	2.52	3.23	2.82	1.33	1.70
H_2O below 110° C.		0.97	1.94	0.59	1.12	0.95	1.08	3.35	0.96	0.76
H_2O above 110° C.		1.88	2.64	0.69	0.77	2.00	1.88	4.06	1.20	0.67
TiO_2		0.87	0.62	0.99	0.61	0.82	0.72	0.64	1.34	1.54
ZrO_2						0.02				
CO_2		None	None	1.35	None	None	None	None	0.38	0.55
P_2O_5		0.27	0.31	0.30	0.30	0.26	0.22	0.24	0.39	0.43
F						None				
MnO		0.09	0.07	0.12	0.04	0.09	0.08	0.05	0.11	0.14
BaO						0.11				
SrO						0.13				
		100.19	100.49	99.66	99.93	99.94	100.15	100.56	100.50	100.21

1. Latite. One mile northwest of McLaughlin's well. Partial analysis by E C. Sullivan.

2. Pyroxene-hornblende andesite. One and one half mile northeast of Black Butte. Analysis by George Steiger.

3. Pyroxene-hornblende andesite. Two thirds mile northeast of Columbia Mountain. Analysis by George Steiger.

4. Pyroxene-hornblende andesite. One mile northeast of Columbia Mountain. Analysis by George Steiger.

5. Hornblende-biotite andesite. One mile northeast of Black Butte. Analysis by George Steiger.

6. Dacite. One half mile northeast of Columbia Mountain. Analysis by George Steiger.

7. Dacite. Diamond Peak. Analysis by George Steiger.

8. Dacite vitrophyre. One mile northwest of Blackcap Mountain. Analysis by George Steiger.

9. Olivine dolerite. Rabbit Spring. Analysis by George Steiger.

10. Mica dolerite. Two miles east of Black Butte. Analysis by George Steiger.

Faulting has played some part in producing the present structure of the Goldfield district, the principal dislocation recognized being the nearly north-south Columbia Mountain fault.

This has been traced from a point nearly east of Kendall Mountain to the eastern end of the town of Columbia, a distance of two miles. It dips to the east at angles ranging from 20° to 55° and has a normal throw. The amount of this is not measurable but may be 400 or 500 feet. The fault appears to end about 600 feet northwest of the Red Top mine, the dacite at this place passing westward across the line of dislocation. South of the end of the fault the dacite is much fissured and the great ore bodies of the Red Top, Mohawk, Combination, Jumbo and Florence mines occupy a zone of great disturbance which lies in the general path of the Columbia Mountain fault. Throughout this entire zone the dacite is traversed by an extraordinary number of fissures which carry soft gouge and which in the aggregate undoubtedly record much movement. There is at present, however, no evidence that the dacite sheet as a whole has been displaced to anything like the extent it would have been had it been affected by the total movement represented by the Columbia Mountain fault. The hypotheses suggested as best accounting for the facts at present known are: (1) That the dacite was intruded after the main movement along the Columbia Mountain fault had taken place; (2) that the intruded magma to some extent followed the fault, possibly in some places coming up along it, and spread out where opportunity offered into sheet-like or laccolithic form; (3) that the Columbia Mountain fault continued, after the intrusion, to be a line of structural weakness and movement; and (4) that such renewed movements along the fault produced in the dacite, lying athwart the path of the dislocation, stresses which were relieved by complex fissuring of the brittle mass. Other stresses probably also contributed to this result, but it is believed that this revival of movement along the Columbia Mountain fault had a very important part in the fissuring and mineralization of the remarkable little area which has produced nearly all the gold thus far mined in the district.

Undoubtedly much remains to be learned regarding the configuration of the under surface of the dacite. This has been reached now in over a score of shafts, but these are not all so placed as to afford the most geological information. In most

places the rocks at the contact are soft and the shafts closely lagged, so that for information concerning the change of formation the geologist must depend upon the memories and observations of those who performed the work of sinking; elsewhere the rocks are mineralized, as in parts of the Mohawk and Mushett mines, and their original character is thereby obscured. Some of the movements that have disturbed the rocks in this part of the district have affected the under contact of the dacite and probably in part caused the local softening which is its prevailing characteristic. The soft, gouge-like material in the Goldfield Merger shaft is reported to be about twelve feet thick.

Without much question some of the irregularity in the lower surface of the dacite is due to a step-like structure produced by faulting. It is not possible at present to identify any of these faults at the surface or to trace them from point to point underground.

(*To be continued.*)

CANANEA MINING DISTRICT OF SONORA, MEXICO.[1]

S. F. EMMONS.

INTRODUCTION.

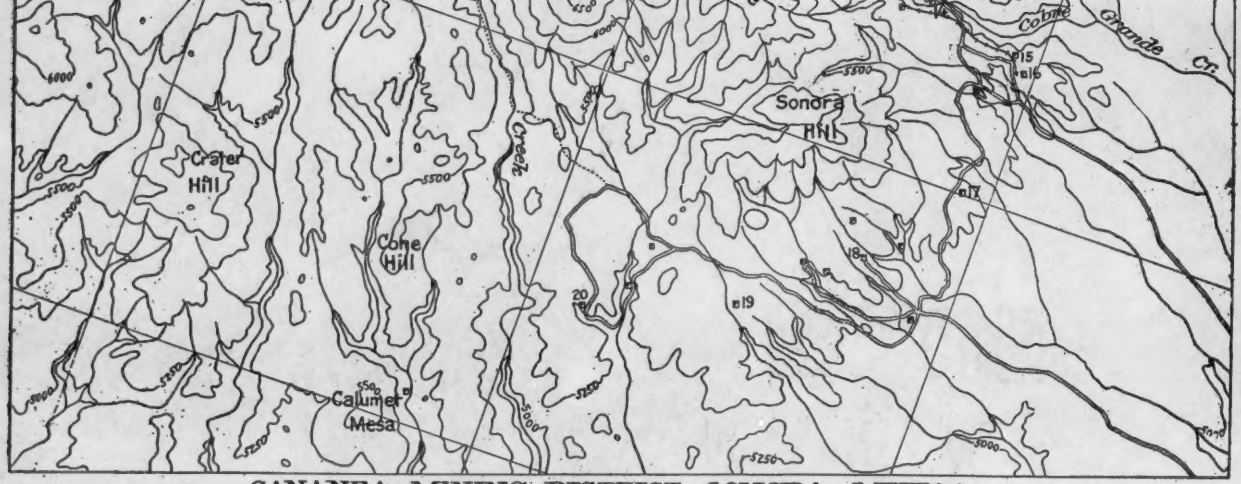
The Cananea Mountains are situated in Sonora, Mexico, directly south of the Huachaca Mountains in Arizona. The town of Cananea at their eastern base lies 25 miles south of the international boundary, approximately in 31° north latitude and 110° 30′ longitude west from Greenwich, and is connected with the boundary town of Naco, near Bisbee, Ariz., by 38 miles of standard gauge railroad.

As seen from the line of this railroad or from the northeast, the Sierra de Cananea presents the general form characteristic of the so-called Basin ranges. That is, it consists of a series of ridges that rise abruptly out of broad, gently sloping valley plains, and represents the upper portions of an older and much wider mountain uplift that projects above the accumulations of Quaternary gravel and silt that have filled the surrounding valley, in places to depths of several thousand feet. As contrasted with the Arizona and Nevada ranges it supports an unusually abundant vegetation, a considerable open growth of coniferous trees having been found on its upper portions, while its lower slopes and the bottoms of the streams that radiate out from its base are well covered by live oak and other deciduous trees. It is, moreover, less symmetrical in shape, being made up of several individual ridges, the most important of which have a northwest-southeast trend, which conforms with the larger features of geological structures, while the average direction of the range as a whole is more nearly north and south.

[1] In the summer and autumn of 1907 a special topographical and geological survey of this district was made under the direction of the writer by R. H. Sargent, topographer, and J. M. Boutwell, L. C. Graton and W. H. Emmons, geologists, during short leaves of absence from their respective official duties in the U. S. Geological Survey. The principal scientific results of this survey are published in the present article by permission of the officers of the Cananea Consolidated Copper Company, at whose expense it was made.

LEGEND
BUILDINGS SHAFTS TUNNELS
NAMES OF SHAFTS AND TUNNELS
1 CAMPANA SH.
2 CAPOTE NO.2 SH.
3 CAPOTE NO.17 T.(OVERSIGHT)13 " " " NO.2SH.
4 ESPERANZA NO.1 SH.
5 VETA GRANDE NO.5 SH.
6 DEMOCRATA SH.
7 COBRE GRANDE NO.5 SH.
8 KIRK NO.9 SH.
9 KIRK NO.10 SH.
10 COBRE GRANDE SH.
11 CANANEA CENTRAL
12 BONANZA NO.1 SH.
" " " NO.2SH.
" " " NO.3SH.
15 CANANEA-DULUTH
16 " " " " "
17 LA PRIETA SH.
18 CANANEA-BISBEE
19 SOUTH CANANEA
20 CALUMET AND SONORA
21 COLE SH. AND T.
NOTE—NORTH-SOUTH AND EAST-WEST LINES ARE AT TWO (2) MILE INTERVALS
N
Mariquita Mountain
Puertecitos
Creek
Alfredeña Ridge
Elenita Mtn.
Elenita Creek
Henrietta
Trail
Creek

Pinal Creek
Pavo Real Creek
Elisa
Elenita Mtn.
El Tobre
Kirk Mtn.
Teocalli
Campana Saddle
Chiva Peak
Chivatera
Democrata
Rompullo
CANANEA
Cerro de Cobre
Sonora Hill
Crater Hill
Huacoldo Creek
Turicia Creek
Cobre Grande Cr.
San Pedro Creek



CANANEA MINING DISTRICT, SONORA, MEXICO

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It is the central of these ridges, the greater part of which is the property of the Greene-Cananea Copper Company, of which the present article specially treats. To the northwest of this, separated by the valley of Puertecitos Creek, the Mariquita Mountain mass forms the northern extremity of the uplift, while to the south and west the Sierra merges into low broken hills.

The drainage, which is through deeply incised and irregularly winding ravines, flows on the east through Puertecitos, Pinal, Pavo Real, Elisa and Capote gulches into San Pedro Creek, which is a tributary of the Gila River of Arizona, and on the south through Huacolote and Tinaja creeks into the Sonora River, which empties into the Gulf of California.

These streams all have a small flow of water, which is perennial in their upper portion, but more or less intermittent in their lower courses. The region has, however, comparatively abundant precipitation, and during the thunderstorms which are of almost daily occurrence during the rainy season—from June to October—these little streams often become for a short period raging torrents.

Capote Creek, the southernmost of the eastward flowing streams, has a remarkable bend in the lower part of its course within the hills, changing from southeast to due north for about half a mile, then curving eastward around the mesa-like spur upon which the old town of Ronquillo and the present concentrating and smelting works are situated. The new town of Cananea is built upon the wider, more level portion of the mesa eastward and further from the steep mountain slope. The valley of Capote Creek from the bend up to the base of Chiva Peak widens out into an oval valley about a mile in length, known as Capote Basin, in which are situated the most productive mines of the region and the miners' towns of Chivatera and Buena Vista.

The relative position of the mines in the district may be seen on the accompanying map, which is a reduction of that prepared by Mr. Sargent. Commencing at the northwest end they are:

1. The Puertecitos mines, in the limestone ridge that forms the northwestern extremity of the uplift and overlooks the broad

shallow basin of Cuitaca Creek to the west and north, which is entirely carved out of granite or grano-diorite. Other mines have been opened in the same body of limestone along Elenita Creek and around Elenita Mountain, south of Puertecitos, but are not actively worked at present.

2. The next important mine is the Henrietta, with ore bodies at the contact of diorite and quartz porphyries, situated at the point where Pinal Creek emerges from the steeper hills into the more open valley of Puertecitos Creek. At the head of Pinal Creek is a mine in limestone, no longer worked, known as the Union Mexican.

3. Next south is the Elisa mine, at the very head of Elisa gulch, with ore bodies in limestone along the footwall or southwest of the Elisa fault, which is the one great structural fault of the district. Across the ridge to the south, or in the northeast part of Capote Basin, are the Sierra de Cobre properties, with ore bodies in limestone like the Elisa, which formerly belonged to the Phelps Dodge & Company interests, but now are the property of the Cananea Company.

4. The mines of the Capote Basin are, at the base of Chiva Peak and west of the miners' town of Chivatera, the Capote mine, and along the south slope of Capote Basin from west eastwards, the Oversight, the Esperanza, and the Veta Grande mines. In the east part of the basin, beneath the bend of the creek, is the Democrata mine, a small independently owned property, the only one within this large area that is not controlled by the Cananea Company.

5. East of the Democrata mine on the low ridge that separates the steep mountain slopes from the fringing mesa, are the Kirk mines, and south of them the Republic mine, while southeast from the Kirk mines along the major strike of the ore bodies are successively:

6. The Cobre Grande, America, Bonanza and Cananea-Duluth mines, all in the mesa country which forms a fringing border to the steep mountain slopes. The most important of these is the Cananea-Duluth, which has been opened since the merging of the Greene and Cole interests.

All these mines are connected with the reduction works at Ronquillo by the tracks of the company's narrow gauge railroad, over thirty miles in length, which winds in and out, through and over the hills in every direction. A central power plant at Ronquillo distributes compressed air also to the drills in all these widely separated mines.

History and Development.—The great amount of iron-stained rock on the surface throughout these mountains must evidently have attracted the attention of prospectors in very early days. The gossans are especially abundant in the Capote Basin, where they form projecting ridges and cover entire mountain slopes. From one glory hole or open cut working in such gossan near Capote Pass, an iron flux that carries upward of 50 per cent. of the metal has been mined since the starting of smelting by the present organization. Moreover, at the heads of most of the various gulches around the mountain mass known as the Cerra de Cobre there are remarkable looking crags of a heavily iron-stained conglomerate, which on closer examination proves to be stream gravels of an earlier period in the physiographic history of the mountain, that were cemented by iron-bearing waters proceeding from the oxidation of the pyrite with which the mountain mass is most abundantly impregnated, and which, owing to the superior resistance of this iron cement, have been left behind as the corrosion has deepened the lower parts of the gluches.

Of the earlier Spanish workings there are rather indefinite traditions. Velasco says that the mines were worked before the eighteenth century by the House of Guco, and that later, after they had long been abandoned by them, José Perez of Avispe, the capital of this department, took out several thousand quintals (hundredweight) of copper ore which were carried overland to Guaymas and shipped from there to Europe. The country has always been in danger of raids by the warlike Indian tribes, the Yaquis and Apaches, by whom more than once the inhabitants have been massacred or driven out, and mining operations consequently suspended.

Finally it is said that in 1865 General Ygnacio Peschirea

(Pesquiera) with an escort of 500 soldiers established a camp at Ronquillo, and erected a small smelting plant, now known as Cananea vieja, two miles below its present furnaces. Mining and smelting operations were carried on in a desultory way for fifteen years. Ore was taken from the Cobre Grande Ronquillo, Campana and San Ygnacio (now Elisa) mines, and smelted to matte, which was transported on mule back to Guaymas and thence shipped to Swansea, England.

About 1881 the Alfredeña, Cananea, Union Mexicana and other mines around the Puertecitos limestone mass were sold to a Cleveland company, whose superintendent, Williams, erected a smelter at Cajoncita, on Cuitaca Creek, at the foot of the mountains about ten miles west of Puertecitos. Ore averaging 20 per cent of Cu and 15 oz. Ag was smelted, and operations carried on for about two years. This smelter was then removed to Puertecitos, to which coke was hauled from Fairbanks on what was then the A. T. & S. F. Railroad, and where it was operated for a year and then abandoned.

The properties around the Cobre Grande at the southeast end of the range were bonded first to Charles Benham, of New York (up to 1886), and later to Major Morton in the interest of F. Aug. Heinze. After taking out about $110,000 in copper matte this bond was abandoned in consequence of the death of Major Morton.

Col. W. C. Green then obtained from the widow of General Pesquiera and other owners, control of practically all the mining properties in the Cananea Mountains. After fruitless endeavors to permanently interest Daly and Rogers, of Butte, Farrell of Ansonia, Conn., and others in developing the properties, Colonel Green organized the Cananea Consolidated Copper Company (Mexican organization) and later floated the stock of the Greene Consolidated Copper Company (holding company) on the New York stock market, which was subsequently (1906) merged with the Cananea Company.

The first smelting furnace was blown in about May 20, 1899, the first concentrator built in 1900, and the narrow gauge railroad connecting this with the several mines completed in 1902.

The great Capote ore body was encountered in May, 1900, and the Oversight ore body, after adjudication of litigation with the Indiana-Sonora Company, was struck in December of the same year.

Active operations of the modern organization may be considered as having commenced with the completion of the Broad Gauge Railroad connecting Cananea with Naco, about July, 1901.

GEOLOGICAL HISTORY.

Age.—The Cananea Mountains are made up to so great extent of much altered eruptive rocks that it is very difficult to decipher their geological history. The few sedimentary beds that do occur are quite barren of recognizable remains of ancient life, so that it is only by analogy and lithological resemblance with the nearest known beds, that their age can be determined.

On these grounds the considerable thickness of quartzites and overlying limestones that occur have been with reasonable probability assumed to be of Cambrian age, and to correspond to the Bolsa quartzites and Abrigo limestones of Bisbee, Ariz., as determined by Ransome. The older granite complex on which these beds rest must therefore be of pre-Cambrian age.

The most careful search has failed to discover any trace of Cretaceous sediments in this range, though they are known to occur in the broad valley to the north and in the next range to the eastward. It is assumed, therefore, that it was not submerged during the Cretaceous transgression. On the other hand, as the greater part of the igneous rocks which now cover its surface are intrusive, it is quite possible that at the time of their intrusion the range may have contained some remnants of Paleozoic formations later than the Cambrian, which have since been removed by erosion.

The greater part of the present surface is occupied by igneous rocks, mostly intrusive, of which twelve different varieties have been recognized and designated by specific names. On grounds of analogy and lithologic resemblance it is assumed that these were erupted in early Tertiary times.

The following are the subdivisions of rock formations that

were adopted in making the geological map of the district, with the local names derived from the place of their most typical development. They are given in chronological order, as far as their relative ages could be determined, though, as is apt to be the case with eruptive rocks of the same general type such as occur here, the evidence of relative age of some of the less important varieties, as they are found in different parts, is at times a little conflicting:

1. Cananea granite.
2. Capote quartzite.
3. Puertecitos limestone.
4. Mariquita diabase.
5. Huacalote rhyolite.
6. Mesa tuffs and agglomerate.
7. San Pedro andesite.
8. El Torre syenite.
9. Elenita syenite-porphyry.
10. Henrietta diorite-porphyry.
11. Tinaja granite-porphyry.
12. Cuitaca granodiorite.
13. Elisa quartz-porphyry.
14. Gabbro.
15. Later diabase dike.
16. Quaternary gravels and alluvium.

The present work has determined that the following ideas which were more or less generally prevalent among those who have previously studied the district are incorrect:

1. That there is one central body of eruptive granite which forms the core of the range, and has metamorphosed the limestones. In point of fact there are two distinct granites; a pre-Cambrian body on which the oldest sedimentaries, the quartzites, were deposited, and a younger, post-Cretaceous granite, the Cuitaca granodiorite, which has produced part of the metamorphism of the limestone body around Puertecitos.

2. That the diabase eruption was later than that of the granite and than the mineralization, whereas it is really older than all the other intrusions, except the pre-Cambrian granite.

3. That the bedded tuffs were among the latest manifestations of igneous activity in the region, and followed the principal mineralization, whereas the present investigation has shown that the explosive eruption which produced these tuffs was one of the early phases of volcanic action, having been preceded only by the intrusion of the Mariquita diabase and the Huacalote rhyolite,

and that they have been mineralized, and contain important ore bodies where they have been intruded by the Henrietta diorite or Elisa quartz porphyry.

ROCK FORMATIONS.

Cananea Granite.—This is the oldest rock in the district, since it forms the basement complex upon which the oldest sediments, the Capote quartzites, were deposited.

The type rock is a coarse microcline granite with prominent quartzes and occasional indications of mica, now altered to chlorite. The feldspar crystals are large, up to an inch in size. There is a fine-grained phase which is almost porphyritic in texture. Its groundmass, consisting of quartz and orthoclase, is unusually rich in quartz, which occurs in small rounded grains, so that it might easily be mistaken for a conglomerate.

The principal mass of this rock, and practically the only exposure in the district, has been traced northwestward continuously from Chiva Peak, at the western boundary of Capote Basin, to the end of the road leading up Elenita gulch, thus occupying the upper part of Capote gulch and the ridge dividing that from the Huacalote-Tinaja drainage, and part of the northern slopes of Elenita Peak, an area about three miles long by one half to three fourths miles wide. The fine-grained phase is found along the summit of the ridge running back from Chiva Peak. The Capote quartzite rests on it on the east, and on the northeast it is cut off by the Elisa fault, which runs northwestward across the heads of Elisa, Pavo Real, and Pinal gulches.

Capote Quartzite.—These quartzites are quite uniformly granular, and rather pure, being brownish on the weathered surface, but almost invariably white underground. In the vicinity of ore bodies they are apt to be rather unctuous, probably by reason of the development of sericite. Where they cross Capote gulch they are arkose at the base, and the conglomeratic phase increases from there to the head of Elisa gulch, where it is a few feet in thickness.

The principal surface exposure of quartzite forms a band about a quarter of a mile wide extending from Capote pass along

the east face of Chiva Peak, to the pass between the head of Elisa gulch and Pavo Real gulch, where it is cut off by the Elisa fault. The beds have a rather steep dip to the northeast, the angle steepening toward the north until they are overturned at Kirk Peak.

They are brought up by faulting in several narrow north-south strips in Capote basin, but they are not known with certainty in any other part of the area.

Puertecitos Limestone.—In the few places where the limestone is fresh and unaltered it is a nearly black, dense fine-grained rock, almost like an argillite. It is moderately heavy-bedded, and certain horizons, especially near the base, are so cherty that they stand out on weathering. Most of the limestone is more or less altered, the least profound phase of alteration being marmorization. There are four areas of marble of noteworthy size, the most important extending from Campana shaft in Capote basin to beyond the Elisa workings, in which are the quarries that formerly furnished the smelter flux. This carries five per cent. of magnesia, with four per cent. of silica and other impurities.

Just east of Elenita Creek, on the road from Puertecitos to Elenita it is altered to a dense pink hornstone, which, though hard as flint, carries only 55 to 60 per cent. of silica.

In other places the limestone is mostly altered to massive garnet rock, with epidote, fibrous pyroxene (Hedenbergite) and specularite (the latter along fracture zones) as subordinate occurrences.

Within the marbleized areas are often patches of garnet and epidote, especially where copper minerals have formed.

The garnet rock is of greenish-brown color, and somewhat greasy. When greatly altered it becomes a mixture of finely divided silica and limonite that may be taken for a gossan. Another phase of alteration produces a soft material like decomposed porphyry which is soon obscured by a slide of harder rock, and does not outcrop in ordinary surfaces, though a slight greenish color and mottling of iron oxide may be seen.

There are three principal exposures of limestone, or its alteration products. The northernmost is a north-south band with

rather waving boundaries, about a mile and three eighths long by a quarter wide, that extends from a little north of Puertecitos southward to the head of Elenita gulch. It lies between Cuitaca granodiorite on the west and Henrietta diorite-porphyry on the east. In and around this occur the most distinctly contact-metamorphic ore deposits. At the head of Pinal gulch, around the Union Mexicana mine, is a small patch of garnet rock, in a line with an eastwardly projecting nose of the Puertecitos body, which suggests a possible underground connection between the two.

A body of garnet rock of similar size extends southeastward from Elenita Mountain, along the ridge separating Huacalote from Tinaja Creek. It contains small patches of contact metamorphic ores, which as yet have not proved of economic importance.

The third and most important exposure extends from the east base of Kirk Peak southeastward across the head of Elisa gulch and over the greater part of Capote basin to the Democrata mine, a distance of about two miles. It here rests conformably upon the Capote quartzite, and like it has a general northeasterly dip, with some local variations. In Capote basin it attains an extreme width of nearly a mile, but is much broken by faults, and by the diorite porphyry intrusions. Underground workings show that the original limestone was more extensive than the present exposure, notably in the Veta Grande and Kirk mines. Small patches of garnet rock are found at the surface as far south as the Bonanza No. 1 shaft, which appear to be entirely surrounded by diorite-porphyry.

No trace of organic life has been found in the limestone, and it has not been found possible to make even an approximate measurement of the thickness of either quartzite or limestone series. It is not thought likely, however, that this much exceeds that of Bolsa quartzite and Abrigo limestone of the Bisbee district, which according to Ransome aggregate 1,200 feet in thickness, and have been correlated with the Tonto formation of the Grand Canyon, the Apache of Globe, and the Coronado of Clifton-Morenci.

Mariquita Diabase.—This, the earliest intrusion in the district, is a rather basic rock consisting essentially of plagioclase feldspar, pyroxene and magnetite. The typical rock has large white tabular feldspar in a fine-grained, greenish groundmass, which often stands out so prominently on the surface as to have led to its designation by the miners as "bird's track" or "bird's foot" porphyry. Away from the central mass the rock is generally finer grained, the phenocrysts being less common, and the feldspars cubical in shape instead of lath-like. Locally scattered grains of primary quartz can be found which sometimes combine in rounded masses that look like amygdules.

The typical rock is very prone to epidotic alteration, the periphery of considerable masses becoming almost solid epidote. When very much altered the rock becomes quite soft, light in weight, and rather chalky in appearance. Near Capote basin, where silicification has also taken place, the surface is pitted by casts of dissolved-out feldspars. It is often strongly impregnated with pyrite, whose decomposition produces much of the abundant gossan observed on the surface.

As its name indicates, this rock forms the principal mass of Mariquita Mountain, where it has a marked bending that dips about 40 degrees northeast, and strikes N. 30° W. It is there flanked on the west by Cuitaca granodiorite, which cuts it, and on the east by the Mesà tuffs which cover it on the lower spurs. From the summit it extends in a long narrow exposure to the northern base of Tascalli, forming both walls of Puertecitos Canyon, and being cut by intrusions of Henrietta diorite and Elisa quartz porphyry. Smaller areas are exposed on the northern slope of Elenita Mountain, at the northern end of Alfredeña Ridge, and southeast of Elenita Mountain, at the head of Tinaja Creek. In the southern half it was not observed, except in a small outcrop within the Huacalote rhyolite area, whose age relations are not quite clear.

Huacalote Rhyolite.—This rock is pink, gray or light-green in color, and porphyritic or glassy in texture. Its small phenocrysts are mostly orthoclase, with locally numerous rounded quartz crystals. In the dense glassy phases no phenocrysts are

seen, but the microscope discloses orthoclase, a little altered biotite or hornblende and some magnetite. In places the rock is spherulitic, the spherulites standing out on the surface about pea size.

It is found only along the southern margin of the area mapped where its outcrops occupy either side of the canyon of Huacalote Creek, and extend about two miles north on the ridge marked by Calumet mesa and Cone Hill. It there has the same relation to the mesa tuffs as does the diabase on Mariquita Mountain.

Mesa-tuff.—The mesa-tuff in bedded form encircles the range on the north, east, and south, dipping away from it at angles which decrease with the distance from the range, and gradually disappearing beneath the covering of Quaternary gravels. In the town of Ronquillo it dips at about 15°, and where it laps up onto the spurs of Mariquita Mountain its angle is as high as 25°. Small outcrops occur on the western and southern slopes of Elenita Mountain, where the bedded structure is not so distinct.

The tuff is composed of angular fragments of igneous rocks or of the minerals of which they were composed, mainly feldspar and quartz, among which the fragments of those rocks that form the near surface are apt to predominate. At the base of the tuffs, especially around the flanks of Mariquita Mountain, the material is very coarse—the rock fragments reaching four or five feet in diameter.

In color the finer grained tuffs are purple, pink or olive green, and in the mines they are bleached white. They are locally much altered, with development of epidote and chlorite. The angular shape of the composing material, the repeated alterations in size of grains, together with their generally increasing fineness toward the top, suggest that it is the result of successive explosive eruptions, and that the bedding is due to subaerial rather than subaqueous deposition.

San Pedro Andesite.—At various points in the Mesa country along the east flanks of the range are outcrops, often covering a considerable area, of lavas, which are interbedded with the Mesa tuffs. They dip eastward with the tuffs, and evidently represent lava flows which were poured out upon the surface during the

eruption of the tuffs. They are so named because they are abundant along the valley of San Pedro Creek, and are mostly andesites, though they have quite a wide range in composition. To the north and east these lavas becomes more acid and porphyritic, and some might be classed as latites. In these pink and purple shades predominate, flow lines are common, the groundmass is often glassy, and there are phenocrysts of acid plagioclase, quartz, and biotite, hornblende being rare or absent. Brown mica is quite abundant in these lavas, and this, together with the flow structure, serves to distinguish them from the intrusive rocks.

El Torre Syenite.—The main exposure of this rock is on the southeast shoulder of Elenita Mountain, where it forms a castellated crag, from which its name is derived.

It is a granular medium-grained rock, of a pinkish color due to the abundant orthoclase which it contains. As microscopic constituents a little plagioclase and pegmatitic quartz with considerable hornblende are visible. Near the contact with garnet rock it contains much epidote as a secondary alteration product.

It is cut by dikes of Elenita syenite porphyry, and is intruded into the limestone. Other direct evidences as to its age are wanting.

Elenita Syenite Porphyry.—This is a fine-grained porphyritic rock, whose predominating feldspar is perthite. It contains also a little acid plagioclase with occasional grains of quartz. When fresh it has a purplish groundmass with small square phenocrysts of feldspar. Except for a local development of biotite no dark silicates have been observed in it. In the sills and portions of the large masses, the rock is very dense, like semi-glassy rhyolite, and has a light color and marked fissility which may represent the direction of flow. In this phase a spherulitic texture is often observed, and the siliceous nodules which stand out on the weathered surface are apt to give the appearance of an oolite or a conglomerate. Evidences of mineralization in it are very scanty. Epidote, pyrite and secondary quartz are very rare. While for the most part a distinctly intrusive rock, the spherulites

and glassy phases indicate the consolidation of some parts near, if not actually at the surface.

There are two principal exposures of this rock. One on the eastern slope of Mariquita Mountain appears to have been intruded as a sill at the base of the Mesa tuffs, and outcrops at several points near the contact with the diabase; the other on the west and south of Elenita Mountain extends for about three miles along the western edge of the area mapped, being separated by a northwest trending outcrop of tuff into two areas, which spread northwest and west from the El Torre syenite body. Here, owing to shattering and brecciation, its line of separation from the tuff is not always distinct. This and the fact that fragments of this rock are frequent in the tuff, make it appear that the two formations are products of the same magma, and belong to the same general period of eruption.

Henrietta Diorite-porphyry.—This is areally the most extensive and economically the most important rock of the region, for its eruption has produced the greatest contact metamorphism and has been followed by the most extensive mineralization.

As a formation or rock unit it is more variable than any of the others and may include more than one individual species. In texture it varies from a medium-grained granitic type through porphyritic to a dense, dark, almost glassy rock in which no phenocrysts are visible, and which resembles an indurated argillite. The fine-grained rock is very susceptible to epidotization, and when thus altered or when bleached may be mistaken for an altered limestone. When fresh the granular phase of the rock is dark-gray in color and has a spotted appearance from the contrast between white feldspars and dark basic silicates. The dense phases, which show no phenocrysts, are dark green to black. The most prominent recognizable minerals are feldspar, hornblende, and biotite; in some specimens quartz is present in small amount. The feldspars are mainly andesine and labradorite, orthoclase, augite, magnetite and pyrite also occur.

It weathers on the surface very readily to a yellowish white; this outer zone seems to protect the interior, which usually remains dark in the incipient stages of surface weathering. Alter-

ation of this rock has been very intense in the region of maximum mineralization. Sericite has developed from the feldspars, the ferromagnesian minerals have been altered to muscovite, and chlorite and much pyrite have been added, by whose oxidation it becomes iron-stained.

Primary pyrite is more frequent in it than in most of the other rocks, both impregnating the mass and in little flakes along joint planes.

It appears to have been the most important agent of contact metamorphism, for it is almost always found with garnet, and it produces garnetization in limestone wherever both rocks occur together. Its abundant content of pyrite and epidote leads to the belief that its magma was rich in mineralizing solutions.

In the Henrietta mine, from which it derives its name, all varieties of the rock, from the coarse-grained granitoid, to the dense black aphanitic rock, occur. It is typically developed on the north side of the knob opposite Puertecitos store.

It is difficult to give in words a clear idea of the distribution of the rock included under this rubric, the area occupied by its exposures being so irregular in shape. It occupies the whole mountain mass of the Cerro de Cobre, except some intruding patches of quartz-porphyry, and extends westward across the Huacalote Basin to the edge of the map. It is in this basin that the coarsely granular phase is principally developed, which is of minor interest as being less evidently associated with mineralization. The Cerro de Cobre mass, which is intensely altered and impregnated with pyrite and quartz, might be considered a center of eruption. It sends off tongues northward into the limestones and quartzites of the Capote Basin, and its area extends into the Mesa country as far eastward as the line of the Cobre Grande and Bonanza shafts. A tongue also extends northward beyond the Elisa fault from the Democrata ground to a little beyond the east base of Teocalli Peak. There are numerous smaller exposures of diorite-porphyry projecting up through the Mesa tuffs in the Mesa country still farther east, especially around the town site of Cananea.

The northern area has the shape of a right-angled triangle,

whose southern base, formed by the Elisa fault, stretches from Elenita to the Elisa mine, and its western side is formed by the Puertecitos limestone body, while the hypothenuse extends from the Elisa mine to the ridge between Puertecitos and the base of Mariquita Mountain. A smaller body separated from this by Elisa quartz-porphyry lies along the west base of the south spur of Mariquita Mountain, and extends into the head of the broader valley of Puertecitos Creek.

While there is abundant evidence that this rock is intrusive, there are places in the fine-grained rock where there is a decided tendency toward bedding. This is especially definite along the railroad, a half mile east of Puertecitos, where the apparent bedding dips northeast at about the same angle with the sediments, and specimens examined under the microscope look tufaceous, thus suggesting that in part it may have been the result of explosive action.

Underground where the rocks have been much altered, as is especially the case in Capote Basin, it is often difficult, and sometimes impossible to distinguish this from the sedimentary rocks. The rounded grains and peculiar sheen on freshly fractured surfaces may serve to distinguish the quartzite, and the more ready effervescence with acid, or in the case of garnet, crystal faces or greasy luster, are criteria to determine limestone origin.

Along contacts of tuff with intrusive diorite porphyry, when both rocks have been bleached and altered, the distinction is peculiarly difficult. Traces of bedding, the presence of calcite, and the shattered condition of the mineral individuals may serve to distinguish the tuffs.

Tinaja Granite-porphyry.—This rock is everywhere quite fresh and shows no evidence of the intense hydro-metamorphism to which other rock formations have been subjected; hence it carries no ore. It is found only in the southwest corner of the area mapped, mostly along the valley of Tinaja Creek, where it cuts both rhyolite and granular diorite. On Crater Hill to the west it is associated with the Cuitaca grano-diorite, dikes of each being found in the other; hence it probably came from the same magma, and is more or less contemporaneous with that rock.

In texture the rock in large masses approaches a granite, and in small dikes is dense and almost glassy, while the color varies from light-gray to pink. The groundmass is microcrystalline or glassy and contains much quartz with orthoclase and some plagioclase feldspar. Phenocrysts of quartz and feldspar are usually present, while the ferromagnesian minerals are biotite and hornblende. Quartz and orthoclase are sometimes seen to be graphically intergrown.

Cuitaca Grandiorite.—This rock, which is a typical granite in appearance, covers the semicircular basin-like area at the head of Cuitaca Creek, in the northwest corner of the area mapped. Its acutal extent beyond this area is unknown, but it is batholithic in character and size. Its outline on the map runs along the slopes of the hills surrounding the basin, which are composed of rocks for the most part older than the granite; viz., the Mariquita diabase on the east, the Henrietta diorite porphyry and Puertecitos limestone on the southeast, and a little Cananea granite and Elenita syenite porphyry on the south, near the west edge of the map.

Beside this one large area, small patches are found adjoining the Cananea granite on the south around the heads of Elenita Creek, between garnet rock and diorite porphyry on the ridge between Huacalote and Tinaja creeks, in syenite porphyry on the west edge of the map, and in four small bodies more or less completely enclosed in the granite porphyry area that stretches south and east from Crater Hill in the southwest corner of the map.

The granodiorite is of light pink or gray color, and nearly everywhere medium- or coarse-grained, though at a few intrusive contacts it becomes fine-grained, and at certain contacts with limestone tends to pegmatitic structure. Feldspars are the most abundant constituent, orthoclase and plagioclase being in about equal proportions, yet the rock seems hardly as basic as most granodiorites, the specimen tested having 71.4 per cent of silica. Quartz is very abundant, and biotite is the usual ferromagnesian mineral, though never so abundant as in the Henrietta diorite-porphyry. Hornblende occurs in some specimens. It weathers

in the large rounded boulder-like masses common in granitic rocks, and is rather barren of vegetation.

It cuts the Cananea granite, the Puertecitos limestone, the Mariquita diabase and the Henrietta porphyry, and is therefore distinctly younger than either. It has altered the limestone to garnet and hornstone between Puertecitos and Elenita, and as it contains some ore bodies near the contact, it must be earlier than some phases of the mineralization. In most places, however, it shows no evidence of hydrothermal metamorphism, and is apparently barren.

Elisa Quartz-monzonite-porphyry.—This is the latest rock that has apparently influenced mineralization. It is a distinctly porphyritic rock in which the principal phenocrysts are rounded grains of quartz. When fresh it is greenish-gray in color, and often shows small feldspar phenocrysts, mostly plagioclase, with rare hornblende and altered biotite. The groundmass is microgranular in texture, mostly made up of orthoclase. The quartz crystals are bipyramidal; generally somewhat corroded so that the outline is now nearly spherical. The feldspar crystals are usually small, but in a few instances, notably at the summit of Cerro de Cobre, they are more than an inch long.

When altered, either by weathering or by mineral-bearing solutions, the feldspathic groundmass is bleached, partly by kaolinization, partly by silicification. When the former has gone on without the induration induced by the latter, the rock crumbles and the round quartz grains are exposed without being broken. They may be obscured by a thin coating of kaolin, but the rounded cavities they leave aid in their detection. When silicification has been the predominant process of alteration, the rock is sometimes pitted as a result of the solution of the feldspar phenocrysts. The surface exposures are generally reddish-brown from a stain of limonite.

The main exposure of the rock is a band about three-fourths of a mile wide, extending southeast from the granodiorite body east of Puertecitos to Teocalli, thus including most of the Company's railroad line from Campana saddle nearly to Puertecitos. It here lies between the diabase and diorite-porphyry, and has the

same appearance of a northeast dipping sheet as the latter. The Toscalli mass, however, appears to have forced itself directly through the diabase.

Two smaller, but still considerable masses break through diorite porphyry on Cerro de Cobre, and still smaller ones are found in the northern part of the Huacalote-Tinaja Basin, and as dikes or knobs in various parts of the areas of diorite-porphyry, mesa tuffs, and Puertecitos limestone. The rock may be observed in typical development at Elisa station.

A contact breccia is found on the margin of the large body of quartz porphyry which forms the summit of Cerro de Cobre, in which the fragments are diorite porphyry enclosed in a matrix of glassy quartz porphyry. This breccia also occurs on Campana saddle, and in some bands in Capote Basin.

Gabbro-diabase.—The latest intrusive rocks are the *gabbro,* which occurs as a narrow band between diorite-porphyry and Cananea granite on the ridge east of Huacalote Creek, and in various smaller outcrops in the vicinity, and the *later diabase* dikes and sills which are found cutting almost all the other rocks in the northern half of the area. These two rocks are apparently related, and have no apparent connection with ore deposition. In looking back upon the preceding succession of igneous rocks if we regard this region as part of a petrographic province in which the existing rocks may be considered to have come from one parent magma, it is possible to trace the recurrent sequence which Iddings has formulated as the general rule for such a series of eruptions.

If rocks which have a similar composition and the same general age relation are grouped together as products of a single magma, it is seen that the first eruption of diabase, which may be considered to have proceeded from a magma of mean composition, has been succeeded by recurrent eruptions of more acid and more basic magmas, thus: (1) Diabase, (2) rhyolite, (3) mesa tuffs and andesite, (4) syenite and syenite-porphyry, (5) diorite-porphyry, (6) granite-porphyry, granodiorite, and quartz-porphyry, (7) gabbro-diabase.

FAULTS AND FRACTURE SYSTEMS.

While the Cananea district is fractured and crushed to a remarkable extent, there is singularly little evidence of profound faulting accompanied by great displacement such as is seen in mountain uplifts built up by dynamic stresses, where the rock masses consist largely of sedimentary formations. The only great structural fault in the region is the Elisa fault which has been traced continuously for about three miles, and somewhat intermittently for a mile farther. Its general direction is N. 75° to 80° W., as indicated on the accompanying map, Plate II., but its displacement is not very great, being a downthrow to the north of probably less than a thousand feet. Its movement is apparently of later date than the mineralization of the limestone, but it may represent a recurrent movement along an already determined line of weakness. The general northwestern trend of the principal ore developments and of many of the larger features of geological structure suggest that faulting may have taken place in the sedimentary rocks before the intrusion of the igneous magmas, which has had an influence on subsequent fracturing.

The rock fracturing in this region is such as might be expected to have resulted from the repeated shocks attendant upon successive intrusions of eruptive rock, rather than from the slow mechanical stresses which produce the folding and faulting involved in the uplift of great mountain ranges where the faults can often be traced continuously for miles.

Here the rock masses have been shattered in a most intricate and complicated fashion, and while in the strongly fractured regions like the Capote basin there are abundant well-marked planes of movement, as well as zones of sheeting and brecciation, individual fault planes can rarely be traced continuously over a few hundred feet in a given direction.

The fissure vein in the original conception of the term, that is an open fissure filled by extraneous material, is rarely found. Ore deposition has been largely by metasomatic replacement or by impregnation of the country rock along disturbed zones.

The prevalent observed strikes of fracture systems are:

1. N. 30° W., which is most frequent in the closely-spaced

fissures and breccia zones of the great ore bodies in the mines of Capote basin. This is generally parallel with the quartzite-granite contact of the Chiva Peak massive, which may be conceived to have acted as a buttress to the stresses induced in this basin.

2. A N. 60° W. strike is also prominent among the fractures observed underground, and is the average direction of a line drawn through some of the main ore bodies outside of the Capote basin. It is also the direction of the band of quartz porphyry that stretches from Puertecitos to Teocalli.

3. An east-west direction is that of the fracture zone followed by the main ore body of the Democrata mine, and of the best defined portions of the Elisa fault. The main joints in the Puertecitos limestone run east-west and north-south.

4. A north-south direction is that of certain faults of unknown age parallel to the limestone contacts at Puertecitos, and of some cross faults that join the Elisa fault in the Elisa mine and are distinctly posterior to ore deposition.

5. A northeast direction is the main direction of fissuring in the Bonanza mine and a minor direction of fissuring supplementary to the more prominent ones in other mines.

MINERALS.

As far as our observation went, there is an unusually narrow range of mineral species in the district, at least among those of common occurrence. It is quite possible, however, that some of the rarer occurrences may have escaped observation, since, the objects of the work being primarily commercial, it was not considered appropriate to make special search for rare species.

Among primary metallic minerals bornite, chalcopyrite and sphalerite predominate in contact deposits in limestones, associated with subordinate pyrite and galena, and a little magnetite and specularite. In the deposits in porphyry, pyrite is the prominent mineral, chalcopyrite being relatively rare, and bornite not observed. Zincblende and galena are also present, the former at times in relatively large amounts rather to the exclu-

sion of copper values. Tetrahedrite is also found, but is only occasionally of economic importance.

Among secondary minerals, chalcocite is the important copper mineral of the sulphide zone. In the limestone deposits at Puertecitos massive chalcocite is known to occur carrying as high as 20 per cent. of zinc, probably a secondary enrichment of zincblende by copper-bearing solutions. As oxidation products chrysocolla, malachite and azurite, cuprite and native copper, once formed large masses near the surface that are now pretty thoroughly mined out. The iron gossans are mostly limonite, but also contain at some points considerable anhydrous oxide.

The most common metamorphic minerals are garnet (probably andradite) and epidote. Both are found as alteration products of limestone, but epidote also results from the alteration of igneous rocks far away from any known limestone body. Other lime-silicate minerals are relatively rare. Some amphibole and pyroxene (hedenbergite) were observed, possibly also vesuvianite and zoisite. Sericite is found as a common alteration product of igneous rocks and of quartzite, chlorite being less frequent. Kaolinization is common as a result of weathering, or the action of meteoric waters. Quartz and calcite are uniformly present in all types of deposit, though nowhere in great quantity and the former rarely in distinct crystals.

ORE DEPOSITS.

There has already been considerable discussion with regard to the ore deposits of Cananea, some geologists maintaining a contact metamorphic origin for them, others denying this mode of genesis for the more important deposits. As is apt to be the case in such differences of opinion, actual investigation has shown that there is a modicum of truth in the views put forth by either party to the discussion. Most typical contact-metamorphic deposits are to be found there, as well as those which would generally be classed as of hydrothermal origin, yet it seems evident that they may all be considered as products of the after action of the eruptive intrusions. In some cases two successive periods of mineralization can be distinguished, and it is

susceptible of direct proof that a deposit or a part of a deposit was formed in one period or the other; in others there is still some doubt as to which period the deposit properly belongs.

Again, certain rock types are definitely associated with mineralization through the contact-metamorphic action they have exerted on the rocks into which they have been intruded, and through the fact that they carry ore deposits themselves. These, as has been already stated, are first and foremost the Henrietta diorite-porphyry, and after this, the more acid types, the Cuitaca granodiorite, and the Elisa quartz-porphyry, whose interrelations are, however, not thoroughly known, and which may represent differing phases of the same general eruption. From which of these rock magmas a given deposit has proceeded is likewise not always susceptible of definite proof. The diorite-porphyry, as the more widespread and as more intimately associated with the valuable ore bodies, is regarded as having been the most generally important factor in ore deposition, while each of the other two is known to have exercised a mineralizing action in certain localities, but it is not always possible to determine what special part or phase of a given ore deposit may be ascribed to the influence of either magma.

The study of the eruptive rocks of the district has shown them to possess a certain consanguinity that would lead to the assumption that they proceeded from one common parent magma, and the frequency with which a small percentage of copper has been found in the different varieties of rock occurring there, suggest that this parent magma contained a certain amount of copper. It is easy to conceive that in the successive differentiations of this magma that have produced the different rock types now exposed at the surface, those that produced the three rocks above mentioned may have become unusually rich in this metal.

As regards the method of forming ore deposits from such magmas, it is generally assumed that where an igneous magma is intruded into sedimentary rocks, which are cooler than the magma, the latter commences to consolidate at its contact with the limestone or other intruded rock. In this consolidation certain rock forming minerals crystallize out first, while others more

volatile or fusible, being squeezed out of the cooling mass by the crystallizing process like water out of a sponge, are held back in the still unconsolidated residuum or mother liquor, to be forced in later through the cracks that may have formed in the already consolidated magma, into the adjoining intruded rocks. In this mother liquor will have been concentrated such metals as may have been contained in the magma, in connection with the so-called mineralizers, such as sulphur, boron, fluorine, etc. In this earlier part of the process the magma being under greater pressure and at a temperature above the critical point of water, the solutions still in gaseous form will have more penetrating power and their deposition in the rock masses into which they are forced, being characteristically by metasomatic replacement, will be less dependent upon the existence of large cracks. When deposited in limestone they will be associated with the lime-silicate minerals that are formed only at this elevated temperature. As this so-called pneumatolytic process continues, with the gradually increasing thickness of already consolidated magma the residual solutions that are squeezed out of it will come from deeper and deeper zones and have a continually increasing distance to travel, hence a progressively decreasing temperature. As this temperature gets below the critical point of the substances involved and the solutions have consequently assumed the liquid form, the process becomes a hydrothermal metamorphism, which results in a somewhat differing mineral association, and requires a more extensive fissuring of the rocks to admit a ready passage of the ascending solutions.

At Cananea where it would appear that such a general succession of conditions governing mineral deposition have been repeated with successive eruptions, it is not surprising that the resulting deposits do not always admit of distinct classification.

CONTACT-METAMORPHIC DEPOSITS.

The two principal areas of contact-metamorphic deposits are in the limestone belt enclosing and extending southward from Puertecitos, and the irregular mass which stretches southeastward from the Elisa mine, bounded on the north by the Elisa

fault. Small outcrops scattered through the large area of more or less garnetized limestone east and south of Elenita Mountain show some copper, mostly in the form of chrysocalla at the surface, and prospecting has developed small patches of copper carbonates and oxides, which have as yet yielded no bodies of economic importance.

Puertecitos.—The Puertecitos limestone body lies between Cuitaca granodiorite on the west and diorite-porphyry on the east, both of which have acted as metamorphosing agents. The limestone is extensively marmorized, silicified and garnetized, and the copper minerals are found associated with the garnet in irregular patches which have no very definite structural relations except that they follow joints and show a tendency to form bodies that dip northeast with the bedding of the limestone. In the primary limestone ore as distinguished from other types of deposit, bornite is more common than chalcopyrite. Some magnetite and specularite are found, and in places zinc-blende is quite abundant, with a little galena. The oxidation products are mainly carbonates with some chrysocolla, which, however, do not generally extend to any great depth, sulphides being found comparatively near the surface. Secondary enrichment has also played a less important part in the formation of these ores than those in the porphyry, yet it has rendered individual deposits quite rich; chalcocite is found which carries as much as twenty per cent. of zinc. Though the primary ore is much richer than that in the porphyry, its irregular mode of occurrence, which increases the relative cost of mining, reduces its economic value.

As at present carried on the ore is mined by quarrying on the steep faces of the limestone ridge back of Puertecitos, which is about a quarter of a mile wide between granodiorite on the west and diorite-porphyry on the east, and its crest about 400 feet above the railroad track. On the east faces are three terraces at about 100 vertical interval, provided with mine trains, and the rock as blasted down, is roughly sorted, the waste being trammed to the waste dump at one end of the terrace, and the ore sent down through chutes to the railroad. The mixture of

rock and oxidized ore thus shipped carries about three per cent. of copper. A similar terrace has been started on the west or granodiorite side of the ridge, but this side had not yet been reached by the railroad.

Ore occurs at Puertecitos also in both granodiorite and diorite-porphyry close to the limestone. It follows as a rule fault fissures which are generally parallel to the contact, and have a northeast dip. In these chalcopyrite instead of bornite is the prevailing copper-bearing ore.

Considerable mining was done in early days in the southern end of this limestone belt, on the slope of Alfredeña Ridge toward Elenita, but as the mines are now closed it can only be said that the ores are of the contact metamorphic type. The same is true of the Union Mexicana mine at the head of Pinal Gulch, but tetrahedrite, which has not hitherto been recognized as a contact metamorphic mineral, is found in its ore associated with bornite, chalcopyrite, hematite, and hedenbergite.

Elisa Mine.—The ore at the Elisa mine is of the same general type as the Puertecitos ore, but chalcopyrite is the prevailing copper-bearing mineral, and the ore bodies contain more zinc-blende and pyrite. The limestone is in places marmorized, but in connection with the ore it is generally altered to garnet. The ore bodies are irregularly spaced, but as a rule lie near and to the south of the Elisa fault, or, in the short stretch where the fault is double, between the two fault planes; and their long axis is generally parallel with the fault, yet no connection between ore and faulting could be found, and the weight of evidence goes to prove that the faulting is later than the ore. Branch faults run south from the main fault, which contain dragged-in fragments of ore. The ore bodies are sometimes several hundred feet long and forty or more feet wide. They have been developed for over seven hundred feet below the surface, but are oxidized only down to the first level.

The Elisa fault is nearly vertical, in the upper part, but assumes a gradually shallower north dip in depth. In the upper part it is entirely within the limestone, but gradually approaches the contact as it descends. The limestone in the lower levels has

the normal northeast dip, but in the upper part is much disturbed, and in places dips steeply south.

The diorite-porphyry, which adjoins the limestone on the northeast, appears to have been the main cause of the contact-metamorphism, but the quartz-porphyry which immediately adjoins it, at a distance of a few hundred feet from the contact, may also have exerted some action.

Similar deposits in limestone, differing slightly in mineral association, are found across the divide from Elisa Gulch, at the head of the north branch of Capote Gulch. As at present developed they are smaller and more scattered than the Elisa deposits, but are generally associated with some fracture in the limestone which here strikes east and west, and dips to the west of north. They are about an eighth of a mile from the Elisa fault, and from the nearest exposure of the intrusive, which is here Elisa quartz-porphyry.

Secondary enrichment has evidently played a less important rôle in the contact-metamorphic deposits than in the other ores. Though there are concentrations of chalcocite here and there in the richer bodies, it is not universally disseminated as in the pyritous ores, where, were it not present, the bulk of the ores would be too low grade to work. Their content in silver, though always small, is somewhat higher in these ores than the average, being at times as much as 5 to 10 oz. of silver to the ton.

The reason for the lesser secondary enrichment in limestone deposits may be that this rock, especially when altered to garnet, is less susceptible to fracturing and fissuring, and that consequently the downward leaching waters from the surface find less ready access to the ore bodies.

Other Contact-metamorphic Deposits.—Among the deposits of present economic value, the above are the only ones to which exclusively contact-metamorphic origin can be assigned. Yet in the other areas of more or less altered limestone which are very considerable at the surface, and as proved by mine workings still more extended underground, frequent small patches of copper ore are found which have the mineralogical characteristics of contact-metamorphic deposits, viz., association with garnet,

and predominance of bornite over chalcopyrite. Where workable ore bodies have developed in connection with such deposits it is at times possible to determine either by direct structural evidence or by the character of the ore that there has been an introduction of copper-bearing material since the primary deposition.

The most definite evidence thus far found has been in the Democrata mine, within a body of limestone that lies beneath the bed of Democrata Creek. The ore body in question lies about three hundred feet north of the Democrata shaft, and has been opened from the 300-foot down to the 700-foot level. It occupies an irregularly shaped fracture zone in limestone 50 feet or more in width, that has a general east-west strike and northerly dip. The ore consists of a breccia of rather large fragments of contact-metamorphosed limestone cemented by quartz and metallic sulphides. In this periphery of the ore body it is easy to distinguish the bornite and zincblende of the first generation from the abundant white quartz with iron and copper pyrite of the second generation, while in the central and richer portions it is difficult to determine in the prevailing quartz pyrite ore that which is distinctly of primary or contact-metamorphic origin; though the latter appears to form but a subordinate proportion of the whole ore mass. The presence of considerable chalcocite in these ores shows that they have been secondarily enriched at a still later period, but to what depth this enrichment may extend was not determined.

The limestone mass in which these ores occur is both cut and covered by diorite porphyry, which constitutes the surface rock of the country eastward from Democrata Gulch, until it in turn is replaced by the mesa tuffs around Ronquillo, while on Democrata Ridge, which forms the east wall of Democrata Gulch, several small patches of garnet rock can be detected in the general covering of diorite-porphyry. Good bodies of carbonate ore have been mined from very near the surface downward in two of these patches of garnet rock, the one on the north, the other on the south slope of the little knob (opposite the shaft) that forms the highest point of Democrata Ridge. Both are

in altered limestone cut through or surrounded by diorite porphyry. That on the south slope shows the breccia structure with ore both in breccia fragments and in the matrix. It occupies an E.-W. fracture zone which dips about 50° north and is probably the apex of the Democrata ore body already described, though the ore is not absolutely continuous between the upper and lower bodies. In all these cases the ore has evidently formed more readily in the limestone than in the adjoining porphyry.

In the West Cobre Grande and Kirk mines, whose workings have thus far opened only ground within 200 feet of the surface, considerable ore has been developed along fracture planes that cross both diorite porphyry and limestone, the latter rock being in much larger proportion than at the surface. The mineral association in these ores is similar to that in the Democrata mine, and they occur for the most part near the contact of the two rocks, but not always entirely within the limestone or garnet rock. The fractures are very irregular in direction and extent, being mostly N.-W., crossed by north and northeast fractures, and the ore bodies not continuous for over 100 feet in a given direction, hence rather difficult to follow. The ores are generally of good grade but already at the 200-foot level is an apparent falling off in the amount of chalcocite and an increase in the proportion of zinc in the ore, which indicates an increasing importance of secondary enrichment in producing payable ores.

The deposits above described seem to form a transition series in which contact-metamorphic deposition in limestone has played an essential but successively less important rôle, and the present economic value of the ores has been more and more dependent upon the action of solutions of the second generation, or of hydrothermal origin, together with migration produced by surface waters or secondary enrichment.

It seems best to describe next the economically most important deposits of the region which appear to form the extreme type of hydrothermal deposits, as developed in the district, leaving other intermediate or transitional types for later treatment.

Capote Basin Deposits.—The economically most important ores of the district, which have been extracted from the great mines of the Capote Basin, present the strongest contrast to the contact metamorphic ores of Puertecitos and Elisa type, both in mineral association and mode of occurrence.

The primary ores consist mainly of pyrite with a small admixture of chalcopyrite, and in places considerable zinc blende. They are very siliceous, and their introduction was accompanied by extensive sericitization and silicification of the adjoining country rocks. There tenor in copper is so low that it is doubtful if in the early days they could have been mined at a profit, if they had not received additional copper by downward migration or secondary enrichment. They occur in closely spaced fractures or shear zones that traverse both eruptive and sedimentary rock, and disseminated throughout the adjoining country rock. Although the associated limestones show evidence of contact-metamorphic action in their alteration to marble or garnet rock, the little copper ore they may contain apparently forms no essential or important part of the present ore bodies. Still, in the very large amount of rock that must have been removed by erosion from above the present deposits, it is quite possible that there were concentrations of contact metamorphic ore whose leachings formed an important addition to the accumulations of chalcocite that constituted the extraordinary richness of the present ore bodies within 200 or 300 feet of the surface.

Mine Developments.—The general disposition of the mines in the Capote Basin may be best understood by reference to the map (Plate II.), and the shafts and tunnels there indicated, the principal shaft of each mine being designated by a number. Thus No. 1 is the Campana shaft, the principal opening of the Indiana-Sonora ground, a tract along the north bank of Capote Gulch that formerly belonged to the Phelps-Dodge interests. No. 2 is Capote No. 2 shaft, which has been sunk to a depth of a thousand feet about 200 to 300 feet east of the main ore body of the Capote mine. No. 3 is the Oversight tunnel (called Capote No. 17), which runs about 20° east of south along the east side of the great Oversight ore body, and at 1,400 feet

reaches the Motor tunnel, No. 4 is the Esperanza No. 1 shaft, to the east of the Esperanza ore body, and No. 5 is the Veta Grande No. 5 shaft, which lies likewise to the east, or in the hanging wall country, of the ore body of the Veta Grande mine.

The main ore extraction of these five mines is through the two connecting motor tunnels, which have an aggregate length of over a mile and a quarter. The Capote No. 9 tunnel starts about 500 feet northwest of Capote No. 2 shaft, running first a little west and then east of south about 3,500 feet to a point under the north spur of Cerro de Cobre. The Veta Grande No. 9 tunnel runs a little south of west, 3,000 feet to the same point, but at a level 170 feet lower, the ore being dropped from one to the other through chutes.

The rocks exposed in the Capote Basin are mainly quartzites and limestones, intruded by large masses of diorite-porphyry and extensively fractured and faulted, with later intrusions of quartz porphyry. The latter rock is in small masses within the basin, but more extensively developed in the bounding ridges; to the north at Campana saddle, and to the south along the upper slopes of the Cerro de Cobre, in each of which localities a contact-breccia phase is developed where diorite-porphyry fragments are cemented by the quartz-porphyry magma.

It is very readily apparent at the surface that the area is one of intense mineralization, where there has been a primary solfataric action or introduction of sulphides of the metals in heated solutions, accompanied by silicification and sericitization of the rocks which has rendered them peculiarly susceptible to subsequent alteration; and that this has been followed by extensive weathering produced by atmospheric agents, in which the felspathic rocks are kaolinized and softened, and the metallic sulphides oxidized, in each case the original materials being so disintegrated and decomposed as to be readily abraded. That abrasion has been unusually great here is indicated not only by the fact that the basin has been deeply eroded out of a relatively high portion of the range, but by the extraordinary richness, as compared with the original tenor of the ore, of the zone of enrichment. At the surface, furthermore, the great development

of bodies of iron gossan, resulting from the oxidation of pyrite, is most striking, and evidently first attracted the prospector. They have not, however, proved to be a generally reliable guide in searching for ore, for some of the best bodies have no surface gossan with which they can be directly connected, and under some of the largest bodies of gossan, no extensive bodies of pay ore have yet been discovered.

As regards rock distribution, the Capote quartzites are found at the west end of the basin resting on Cananea granite, with a generally northeast dip, and, except for a narrow northwest band faulted up between the Capote mine and Chivatera, have not yet been seen elsewhere in the basin either on the surface or in the extensive mine drifts.

The limestone rests conformably on it, and in the few places where bedding planes can be distinguished, has also a general northeast dip. It is very largely altered to garnet or marble, and under the great gossan at Capote Pass is changed to gypsum over a considerable area. On the north, where it is sharply delimited by the Elisa fault, it forms an almost continuous belt along the north slopes of Capote Gulch, but from there southward is gradually crowded out by the growing intrusions of diorite porphyry until it is entirely lost sight of under the Cerro de Cobre.

The rest of the area, with the exception of the small bodies of quartz-porphyry, is occupied by diorite-porphyry, prevailingly of the fine-grained or aphanitic phase, which when highly altered is with difficulty distinguishable from certain alteration phases of quartzite or limestone. The form of the diorite bodies appears to be mainly that of irregular stocks, and of wedge-shaped tongues projecting out into the limestone area from the Cerro de Cobre. In the Veta Grande ground to the southeast, however, the increase in extent of limestone in depth suggests that the diorite is there, in part at any rate, in sheet form.

Although the ore bodies may cross all of these rocks, it is in the diorite-porphyry apparently that ore has most readily formed, actual contact-metamorphic ore in garnet rock being in the pres-

ent workings rather a mineralogical curiosity than an economic product.

Both diorites and sedimentary beds have been extensively shattered and faulted, the major or predominant direction of the fault planes belonging rather to the N. 30° W. than to the N. 60° W. system, the latter of which is the more common strike of such planes in other parts of the district. What relation the faulting bears to the quartz-porphyry intrusions is not definitely known; it may have been contemporaneous with and possibly was in part produced by that intrusion.

The best defined faults in the basin are those in the Capote and Oversight ground at the east base of Chiva Peak. Of these the Capote fault is a zone of shearing or faulting running N. 30° W. from the Glory hole at Capote Pass, which dips more steeply northeast than the bedding and thus cuts through limestone and intruding diorite-porphyry into the underlying quartzite. Its displacement is a downthrow to the east. About a thousand feet east of the Capote fault is a second line of displacement, called the Ricketts fault, which dips steeply southwest, thus converging in depth with the Capote fault. In strike it is nearly parallel with the Capote, but tends to diverge and split up to the south so as to include an ever widening zone toward the Cerro de Cobre. Its movement has been an upthrow to the east, which has brought the quartzite to the surface in narrow parallel bands, while the ground between the two faults is a dropped block or wedge in which occur the great Capote and Oversight ore-bodies. The character and amount of displacement on other fault planes has not been determined.

Ore Bodies.—The great productive ore shoots of the Capote basin thus far developed, the Capote, Oversight, Esperanza and Veta Grande bodies, occur in northwest striking zones arranged along the northern flanks of the Cerro de Cobre, with a general parallelism to each other, but each, commencing with the Capote body on the west, set off successively a little more to the west and south, and with a pitch which, when it departs from the vertical, is also to the southeast.

The general relation thus maintained by them to the igneous

mass that forms the Cerro de Cobre is such as might be expected had the solutions from which the ores were precipitated originated at some point beneath that mass.

The *Capote* ore body occurs on the western edge of the downfaulted block between the Capote and Ricketts faults. The central and richest portion has for some years been bulkheaded on account of fire; hence there is some uncertainty about its relation to the limestones which form the greater part of the surface exposures in the interfault block in which it occurs. The gossan above it caps not only the quartzite and porphyry along the Capote fault zone, but also a great width of the hanging wall limestone. The actually stoped area on the motor tunnel level was from 300 to 400 feet in length and up to 165 feet in width, and in this area the ore, as taken from square sets, is said to have never run less than 20 per cent. of copper, and sometimes very much more.

This main ore chimney stood nearly vertical, decreasing in size from a length of 475 feet on the first level to 130 feet on the fourth; a second shoot of somewhat smaller dimensions starts in a little distance to the northwest, and with a general southeast pitch, has been followed down to the 700-foot level, and cut again on the 1,050-foot level. It lies in closely sheeted, altered and somewhat brecciated porphyry at or near the Capote fault, which dips steeply northeast over a footwall of quartzite that is sericiticized and impregnated with pyrite. On the east is limestone traversed here and there by porphyry which extends to the Ricketts fault. At about the sixth or seventh level the ore body passes into a breccia made up of fragments of both quartzite and porphyry, and the limestone to the east is succeeded by quartzite. Some of the fracturing is evidently post-mineral, for traces of secondary enrichment are found down to the seventh level.

The whole mass of the country rock for considerable distances from the central chimneys is more or less impregnated with pyrite, which thus constitutes a disseminated ore body that furnishes concentrating ore, when sufficiently enriched.

The *Oversight* ore shoot lies about 2,000 feet southeast of the Capote chimney, and has practically no gossan directly over it,

the surface consisting of fine-grained diorite-porphyry, highly silicified but only slightly iron-stained. With the great gossan body at Capote Pass, which lies about a thousand feet to the west and at only 300 feet higher level, it has no apparent connection. So great has been the mass of ore taken from it, that the whole northeast slope of Cerro de Cobre, at the base of which it lies, is slipping bodily downward, leaving a fresh vertical wall over a hundred feet high, at the summit of the ridge. It occupies a tongue of crushed diorite-porphyry protruding into the limestone on the eastern side of the interfault block, and is bounded on the east by quartzite brought up by the eastern member of the Ricketts fault, and on the west by limestone, which also has a faulted contact.

The ore is, like that of the Capote, an enriched pyritous ore, but the enrichment which is of chalcocite with a little native copper, is less concentrated, the shoot consisting of a series of lenticular bodies of richer ore, with low-grade ore between. The enriched portion commences at about 200 feet below the surface and is over a thousand feet in longitudinal extent. Sericitization has played a greater part in the alteration of the country rock, and the ore is in consequence more greasy and aluminous. But three levels had been opened in the mine, and the limit of secondary enrichment has not yet been determined.

The *Esperanza* ore shoot is a smaller body to the east of the Oversight and separated from it by 200 to 300 feet of quartzite intruded by diorite-porphyry, which forms part of the fault block brought up to the east of the Ricketts fault. It is of similar composition but very much more irregular in outline. To the east of it lies the belt of limestone which separates it from the Veta Grande ground, and which must necessarily have suffered some downward displacement, for as yet no quartzite has been struck beneath the limestone by the deep workings of the Veta Grande mine. No single well-defined fault plane has been found on which this movement could have taken place, and it was very likely distributed over an irregular zone of considerable width, probably that in which the ore body occurs.

The *Veta Grande* shoot lies in an easterly dipping tongue of

diorite that protrudes into the broad limestone area east of the Esperanza mine and is only 250 feet wide where crossed by the motor tunnel. The ore follows a zone of fracturing and brecciation in this diorite, that strikes northwest and dips northeastward at angles of 40° to 80°. In this zone it pitches to the southeast from its highest point in the ore body at the Massey shaft, above and a short distance west of Veta No. 5 shaft, which was a large mass of exceptionally rich oxidized ore carrying carbonates with cuprite and native copper in a highly silicified and bleached diorite that closely resembles a sugary quartz. From this body downwards in a southeasterly direction the ore has been followed, in practical continuity but with decreasing area and tenor in copper, to the 500-foot level. In the middle levels there is much enrichment by chalcocite, but this enrichment has apparently not extended to the lowest levels.

Limestone is found not far from the ore body both in foot and hanging wall country, but ore is found in similar fracture zones in the porphyry entirely separated from any known body of limestone, notably on the spur to the east of upper Democrata Gulch. Such porphyry ore is generally of lower grade than that associated with the limestone.

IGNEOUS CONTACT DEPOSITS.

Henrietta Type.—The Henrietta mine presents another type of deposits, which may be called Igneous contact deposits, since they more nearly resemble the contact-metamorphic deposits, except that the limestone and lime-silicates are absent. The ore bodies occur along though not immediately on the contact of quartz-porphyry and diorite-porphyry, sometimes in one, sometimes in the other rock. The surface exposure of this contact follows a rather irregular line in a general N. 45° to 55° W. direction from the Elisa mine toward Puertecitos. The mine workings, which have only been opened within two or three years, are situated on either bank of Pinal Creek, where it emerges from the steeper hills; the tunnel on the south side is being driven to connect with a similar opening on Pavo Real Creek to the southeast.

The primary ore consists of chalcopyrite and bornite with pyrite and zincblende in a somewhat siliceous gangue. It contains also occasional tetrahedrite and runs higher in silver than the ordinary quartz pyrite ore. One body 10 feet thick was yielding 6 per cent. of copper with 8 to 10 oz. of silver and about 60 cents in gold to the ton.

As shown in the mine workings, the contact is generally a flat, somewhat wavy surface, with a shallow northeast dip, but in places the diorite is crushed, and somewhat mixed with quartz porphyry. The diorite porphyry in this mine presents varied texture from gray and coarsely granular to fine-grained, black and aphanitic. Where impregnated with ore it is bleached, highly siliceous and often porous.

The ore occurs as cement filling in breccia zones and as rock impregnation or replacement along fractures, or filling joints and veinlets. To judge by present developments, whose extent is somewhat limited, the ore bodies have more of the irregular sporadic distribution of the contact-metamorphic deposits, than the linear arrangement along definite zones of fracture of the Capote Basin deposits, yet they have been as much as 150 feet in length and up to 10 feet in thickness. They are found, as already stated, both in diorite-porphyry and quartz-porphyry, hence must be later than either, and are presumed to be an after-effect of the quartz-porphyry intrusion. Chalcocite and even native copper are found in them, but developments have not been carried to sufficient depth to prove whether they will become of low grade when out of the reach of secondary enrichment.

Cananea-Duluth Mine.—This is the most important among the newly developed ore bodies. It lies in the mesa country about a mile and a quarter south of Cananea, and a half mile east of the steeper slopes of the range that are made up of diorite-porphyry. It is far away from any known body of limestone and entirely surrounded by mesa tuff, but the ore occurs in a protrusion of diorite-porphyry that has thrust itself up through the tuff. This is much shattered and all more or less mineralized, especially along its contact with the surrounding tuff, so that it is in one sense a contact deposit. Yet the contact is not

well defined, it being often difficult to distinguish in the upper levels where the rocks are generally kaolinized, and the contacts observed are mostly slip-planes rather than eruptive contacts as in the Henrietta mine.

The body is of a rather elliptical form, the longer axis having a direction of about N. 60° W., is over 1,200 feet long, up to 150 feet wide, and has thus far been opened to a depth of 400 feet. On the surface the only favorable signs are the brecciated, slightly stained and silicified character of the country rock, which is practically barren for some distance down. The first considerable values commence with the zone of secondary enrichment where primary sulphides are coated with sooty chalcocite. In depth the character of the primary deposition is best seen along the periphery of the body where slip planes and breccia structure are most distinct. Here it is seen to be a mixture of chalcopyrite and pyrite, with some bornite and occasional tetrahedrite, in a quartz gangue replacing the cement of the breccia, which itself consists of the same material as the large fragments but more finely ground-up. The large fragments are themselves silicified and shot through with fine-grained pyrite, and are often made up of clastic material, thus suggesting two periods of mineralization.

Through the middle of the mass ore occurs in small joints or veinlets and as impregnations of the rock, thus resembling "disseminated deposits" in porphyry. The whole is very generally silicified, while the development of sericite is less than in the Capote Basin ores; thus the lower grade material is "dry" rather than "greasy," and hence concentrates better, so that it constitutes a very valuable ore in that a very large proportion of the whole mass can be profitably extracted. The downward limit of secondary enrichment is not yet well defined in this mine, but the grade of the ore does not seem to have fallen off at depths thus far reached.

There are many planes of movements, which, however, are not continuous over great distances, but they rather form zones along the boundaries of the body, those on the north side tending to dip to the northeast, and those on the southwest are nearly verti-

cal or have a steep southwest dip. Where these are wanting, the distinction between ore material and country is the absence of brecciation in the latter. A clastic structure is common to tuff and altered porphyry, and in the latter this sometimes suggests a flow-breccia.

These ores carry more silver than the Capote Basin ores, the tenor being higher where tetrahedrite is more frequent.

Other Deposits in the Mesa Country.—Intermediate in position as well as in character, between the Duluth and the Kirk deposits, are those of the *America* or *Bonanza* and the *Cobre Grande* mines. The latter was one of the early producers of the district, and had so valuable a body of oxidized ore within a hundred feet or so of the surface, that, as shown by the remaining slag heaps, it was smelted on the spot. These old workings being now inaccessible, only a few drifts in the sulphide zone could be visited; but there appears to be a general resemblance in geological relations between these and the more recently opened Bonanza deposits to the south.

In a general way these deposits may be said to have been formed by solutions which rose along a line or zone of fracturing, partially replacing and impregnating the adjoining country rock with pyritous ores, that have been subsequently enriched by downward leaching. This line of fracturing which has a steep dip westward, runs northeast in the Bonanza ground and northwest in the Cobre Grande ground, there being a more or less complete curving connection between the two in the intermediate America ground, and a northwestern continuation of the Cobre Grande fracture being traceable under Watertank Hill in the direction of the Democrata mine. Both in Bonanza and Cobre Grande ground an irregular mass of garnetized limestone lies immediately west of the ore, though not necessarily in immediate contact with it, and the fracture zone is at or near the contact between diorite porphyry and Mesa tuffs. Furthermore in each case there is a so-called flat body, the solutions having branched off and deposited for a limited distance on a plane that dips 15° to 20° eastward and connects with the main vertical fractures, the suggestion that presents itself being that this plane is con-

formable with the bedding of the tuff, which generally forms the country rock of the flat body. The vertical fractures are often double or triple, thus enclosing a considerable area of more or less impregnated country. In the kaolinized and bleached condition of the country rock, it is at times impossible to determine whether a given specimen is diorite or tuff, especially as the former often has a finely brecciated or clastic structure. Yet both rocks are undoubtedly present.

The surface rock for 30 or 40 feet down, in the Bonanza ground, is barren or slightly impregnated with oxides and carbonates of copper. The enriched zone of pyritous ores covered by a coating of chalcocite, and carrying veinlets of fairly pure chalcocite, runs up to 10 per cent. of copper, but the values rapidly fall off with depth, and at 200 feet it is already of quite low grade. The relatively slight extent of secondary enrichment can not be assigned to any want of permeability of the overlying rock material, hence it is assumed to be due in part to a relatively slight amount of erosion, and in part possibly to the fact that the original depositing solutions did not reach a very much higher horizon than the present.

At various points in the mesa country to the south of the Duluth mine shafts have been sunk through the Mesa tuffs, which have developed diorite-porphyry intrusions that are slightly impregnated with disseminated ore, enriched by sooty chalcocite, none of which have as yet found actually productive ore bodies.

To the north of the town of Cananea the *Calumet & Sonora* Company has opened some interesting deposits of a type that differs from any yet described. They occur in a belt of brecciated diorite-porphyry that is cutting through the Mesa tuffs. Not being accessible at time of visit data as to underground relations were obtained from the mine manager. The fractures, which are nearly vertical, have a general 70° Northwest direction and the two shafts are on a N. 60° W. line, but it does not necessarily follow that they are on the same line of fracture. The ores in the southernmost shaft are very varied in mineralogical composition.

The southernmost, or Norton shaft, was sunk 240 feet and developed a vein carrying galena, antimonite, zincblende and chalcopyrite and a little dolomite with 80 oz. of silver to the ton in a diorite-porphyry breccia.

At the northernmost or Topo Chico shaft a so-called dike of breccia about 30 feet in width cuts the purple and greenish tuffs, in the middle of which is a vein of coarsely crystalline galena, zincblende and chalcopyrite practically without gangue. The galena is said to carry 30 ounces and the chalcopyrite 4 to 6 ounces of silver to the ton. The zincblende is of the rosin type and yields over 60 per cent. zinc in carload lots. The vein is a solid mass of metallic sulphides between clean walls 8 to 10 feet wide. A branch makes off at right angles to the main vein which has 5 feet of breccia. The ore first appeared at 20 feet from the surface and was partially oxidized down to 100 feet. The vein itself yields abundant water, highly charged with mineral salts, but the Mesa country rock on either side is quite dry.

Developments in this type of deposit are as yet too limited to determine whether they are merely sporadic local concentrations of ore, or whether they are likely to lead to large and permanent bodies. The fact that they have practically no outcrops, and very little surface indications, render the search for them very uncertain and expensive.

CONCLUSIONS.

In the previous pages the Cananea Mountains are shown to have been an original uplift of Paleozoic quartzites and limestones resting on an older granite, that had been intruded, broken up and partly buried by no less than twelve successive eruptions of igneous rocks, of which most were intrusive, but one at least took the form of an explosive outbreak and spread its materials out upon the surface.

Of these successive eruptions only three have exercised contact-metamorphism upon the intruded limestones, the most marked and wide-spread effect having been that caused by the diorite-porphyry, and to a less degree by the granodiorite and

quartz-porphyry intrusions which followed it. The gabbros and later diabases, which were the final phases of eruptive action, had apparently little or no metamorphic effect, and no connection with the ore deposits.

The ore deposits of the region that have thus far proved of economic value are all included in a belt of country lying along the northeast flanks of the range, from one to two miles wide and six miles long, in a general northwest-southeast direction. Although contact-metamorphism and ore deposition have not been strictly confined to this belt, it is here that the dynamic disturbance of the rocks has been greatest, and their action appears to have been most energetic.

Ore deposition has evidently taken place from highly heated solutions emanating from the cooling magmas and in the deposits themselves it has been possible to distinguish two periods of deposition, one in which they were above the critical point of water and hence in gaseous form, the other in which, though still highly heated and endowed with great penetrative force, the temperature of the solutions had so fallen that they were in liquid form.

In the first period were formed the typical contact-metamorphic deposits in garnetized limestone, such as are being worked at Puertecitos and in the Elisa and adjoining mines. The great ore bodies of the Capote Basin, following fracture zones that cross both sedimentary and igneous rocks, represent the second class. In the Democrata mine both types are combined. In all these cases the ores are characteristically metasomatic deposits, for though some follow certain lines of fractures, the fractures had produced only sufficient open space to admit the circulation of the uprising water, which had penetrated and replaced the adjoining rock from the various movement planes outward. In mineralogical composition the hydrothermal deposits of Capote Basin are essentially quartz-pyrite ores with a little chalcopyrite and zincblende, in original condition probably not averaging more than one or two per cent. of copper. The contact-metamorphic ores in limestone consist of original bornite and chalcopyrite with zinc blende and pyrite, and have a much

higher original content of copper and silver. The variety of mineral species present, both in ore minerals and lime silicate or gangue minerals, is unusually restricted.

Other types represented by the deposits of the Henrietta and Duluth mines, which occur at or near the contact of two varieties of eruptive rock, and away from any known sedimentary rocks, have been provisorily designated igneous contact deposits.

The deposits of the Henrietta mine occur near the rather flat-lying contact between diorite and quartz-porphyry, mostly in the former, but at times also in the latter rock. Although they contain little or no limesilicate minerals, the mineralogical composition of the deposits resembles that of the Puertecitos and Elisa contact-metamorphic ores. The Cananea-Duluth deposits, of similar mineralogical composition with the Henrietta ores, occur in an intrusion of diorite-porphyry cutting through bedded Mesa tuffs, the richer ore being found along brecciated fracture zones on the periphery of the intrusion, which is of elliptical shape, 1,200 feet by 150 feet in its longer dimensions, while in the interior of the mass the porphyry is more or less impregnated with disseminated quartz-pyrite ore. A certain amount of tetrahedrite is found in both types of deposits, and each is rather richer in silver than the average ore of the district.

The Bonanza and Cobre Grande ores are impregnations of diorite porphyry and tuff by quartz-pyrite ore near the contact of the two rocks.

Secondary enrichment has played a rôle of varying importance in the different types of deposits, a difference which has been dependent on physical, rather than on chemical causes. It has been of the greatest importance in the Capote Basin deposits, where out of low grade quartz-pyrite ore, probably too poor to work under ordinary conditions, it has produced the richest ores of the district and those which on account of their great volume and ready accessibility have thus far yielded the greatest amount of copper. The reasons for the great enrichment have been, first, the greater permeability of the enclosing rocks through fracturing and brecciation; second the amount of clay resulting from their alteration, which would have retained the copper

from descending solutions by absorption, and third, the greater amount of overburden removed by denudation from which the enriching material was derived, which was due to their position near the axis of uplift, and further to the probability that this overburden carried rich deposits of copper ore, possibly of contact-metamorphic origin.

To the deposits in porphyry in the mesa region secondary enrichment has also been an important factor, but it has been less in amount and has not extended so deep as in the Capote Basin deposits. This difference may be accounted for by a lesser overburden removed, and the improbability of any contact-metamorphic deposits having existed in that overburden.

In the contact-metamorphic deposits in limestone, secondary enrichment below the zone of oxidation has been comparatively inconsiderable, probably because the garnet rock is tough and does not fracture readily. Chalcocite is found locally, generally in massive form, rather than as the silty sulphide-coating of pyrite which characterizes the porphyry deposits. It seems more abundant in the igneous contact deposits, but at the depths now reached it is not yet possible to determine its amount or extent.

As a whole the Cananea district presents a most interesting field for the study of deposits from mineral-bearing magmatic waters at high temperatures, a field which is constantly being enlarged under the well planned and vigorous system of underground exploration carried on by the present management. In a general way one can trace a change in the character of the deposits as distance from the probable central line increases and the depositing waters may be assumed to have come from lower levels.

As contrasted with other districts where contact-metamorphic processes have been active, many of the differences are probably due to structural causes. Thus in the Clifton-Morenci district, as described by Lindgren, a second period of ore deposition by hydrothermal waters has likewise followed that of contact-metamorphic ores in limestone, but the veins in which the later deposits have formed are described as fissure veins having at

least one well-defined wall. At Cananea the character of the dynamic disturbance was not such as to form well defined fissures.

In both districts, however, deposition has been exclusively a metasomatic process, and in the porphyries adjoining the veins are aureoles of disseminated pyrites which are only payable when they have been enriched by a deposit of secondary chalcocite. On the other hand, the disseminated ores in porphyry, like those of Bingham and Ely, or in schists, like the Miami and Ray deposits, differ from the Capote Basin or Bonanza deposits mainly in that the fracturing has been so slight as only to admit of a general impregnation of wide areas of the country rock, and not of its concentration into considerable masses of ore. They were probably deposited from highly heated waters with great penetrative power, and at Cananea there still remain large areas of porphyry impregnated with pyrite that would probably pay to work, if they had been sufficiently enriched by chalcocite and the conditions were such as to admit of mining and concentrating on a large scale and at very low cost.

The following list includes all the articles on the geology of the Cananea district known to the writer. While these writings were consulted in preparing the present report, no specific reference to them has been made, as it seemed unnecessary where they agree with present determinations, and the differences may be readily explained by the inferior facilities possessed by the earlier observers.

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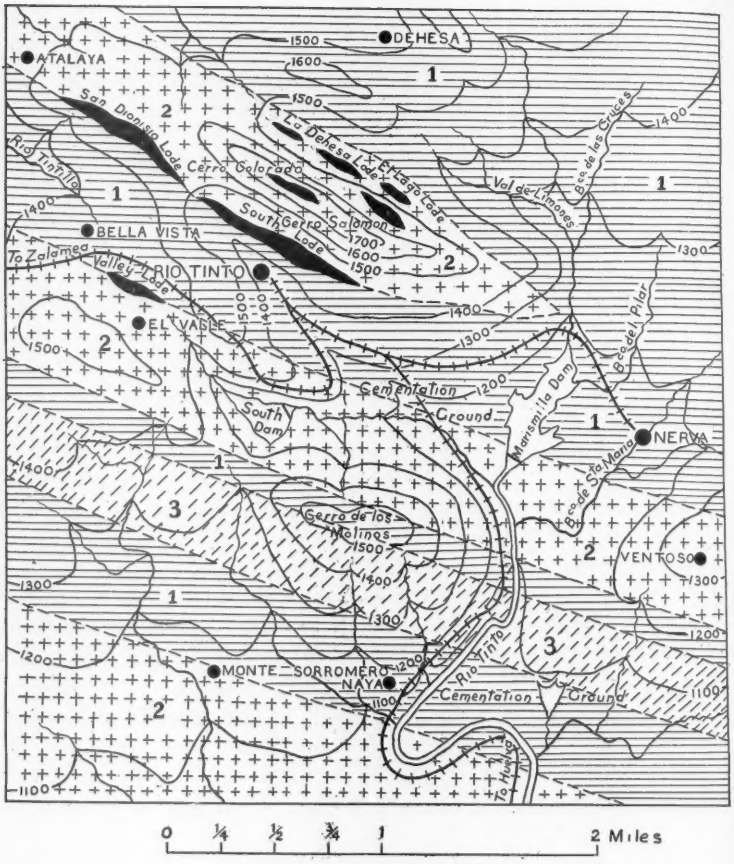

Geological Map of Rio Tinto. Contour interval 100 ft. 1 = Slates (Culm). 2 = Porphyry. 3 = Diabase.

THE PYRITIC DEPOSITS OF HUELVA, SPAIN.

A. Moncrieff Finlayson.

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Part I.—Geology.

INTRODUCTION.

This paper contains the results of an investigation into the pyritic masses of the important copper district of southern Spain and Portugal. The examination of the geological relations and mine workings of some typical deposits, and the collection of ores and of igneous rocks, was carried out during the three summer months of 1909, the subsequent laboratory work being completed at the Imperial College of Science and Technology, London. No geological map of the whole area has been prepared with this work, as the time available in the field was much too short. The map of the Spanish Geological Commission, by Don Joaquin Gonzalo y Tarin (1886–88), is reproduced in several former papers, but some revision of this is necessary in the light of later discoveries and modern petrology.

The attached bibliography[1] contains a list of the chief works dealing with the geology and ore deposits of the field. The most important are the official Spanish memoir, and the papers of L. de Launay (1889), J. H. L. Vogt (1899), F. Klockmann (1894 and 1902), C. Schmidt and H. Preiswerk (1904), and B. Wetzig (1906).

My warmest thanks are here due to Mr. Alex. Hill, Mr. Wm. Frecheville, Mr. Edward Walker and Mr. Robert Addie, of London, for facilities kindly secured through different companies to visit their mines; to Mr. Vice-Consul R. E. Carr (Cordoba), Mr. Vice-Consul Rice (Huelva), Señor Don Carlos Sundheim (Huelva) and the managers and staffs of the different mines visited, for their kindness, and the many opportunities given for underground work; and to Professor W. W. Watts, Professor W. A. Carlyle and Dr. C. G. Cullis, for their constant advice and the many facilities granted in the petrological and metallurgical laboratories.

GEOLOGICAL RELATIONS OF THE DISTRICT.

The copper region is in the southern limits of the Iberian meseta, an old Hercynian fragment which received its structure with the widespread earth movements of late Carboniferous and Permian times, like the central plateau of France, the Harz and other European districts. The folding, along approximately east-and-west lines, was accompanied by intrusions of granites, porphyries and other igneous rocks, and to this epoch belong very many other ore deposits which have enriched the peninsula, including the pyritic deposits of the south, the mercury ores of Almaden, and the lead-zinc ores of central Spain (Linares and Ciudad Real). The disturbances ended with fracturing along the present borders of the tableland, notably along its south-eastern edge, where the valley of the Guadalquiver follows the line of the subsidence thus created.

Ore deposits of tertiary age, accompanying the great Mediterranean movements along the Betic Cordillera and the Pyrenean chain, occur chiefly in these Tertiary zones of disturbance. The

[1] ECON. GEOL., Vol. V., No. 5.

southern part of the meseta is essentially a district of Hercynian mineralization. According to Nognès, however, the gold deposits of Peñaflor and Lora del Rio, between Seville and Cordoba, on the edge of the Guadalquiver fault-line, are of Tertiary age, being connected with Miocene and later basic intrusions.[1]

TOPOGRAPHY.

The mining field occupied a zone extending for 130 kilos (80 miles) through the province of Huelva into Alemtejo (Portugal) on the west, and into Seville and Cordoba provinces on the east. With a few exceptions, all the important deposits are in Huelva. The town of the same name, situated on the south coast at the estuary formed by the confluence of the rivers Odiel and Tinto, is the chief town of the province, and with the development of the mining industry, followed by extensive harbor improvements, it has risen to be one of the chief shipping centers in Spain.

The country slopes up gently from the sea-coast to the Sierra Morena, which forms the natural watershed. The chief streams are the Odiel, the Tinto and the Piedras, all flowing south into the Atlantic. The general topographic features are simple, the limits of the geographic province being determined by the northern Sierras, which attain a height of from 600 to 1,000 meters, and by the great catchment-basins of the Guadiana and the Guadalquiver on the west and east, respectively. The river systems are well incised and in a mature stage of dissection. The surface of the country has a uniform slope from the sierras to the sea, the ridges are even, and the summit levels show general accordance. There is an absence of commanding heights or bold ridges, except where differential erosion has resulted from the presence of belts of more resistant rock, and the district is free from marks of youthful drainage. It is clearly a dissected peneplain, which is once more well advanced in the present

[1] M. A. F. Nognès, "Gisement d'or á Peñaflor," *Comp. Rend. Acad. Sci., Paris,* XCVIII., 1884, p. 760; "El oro de la sierra de Peñaflor," *Bol. Com. Map. Geol. Esp.,* Madrid, XII., 1885, p. 247; "Gisements aurifères de l'Andalousie," *Bull. Soc. Ind. Min.,* St. Etienne, XIV., 1885, p. 931.

erosion cycle. The chief streams flow due south across the strike of the rock formations, while the weaker tributaries occupy valleys more or less at right angles to the main valley, *i. e.*, along the strike of the formations, whose disposition in parallel belts of varyingly resistant rock has influenced their direction of flow.

The climate is warm and healthy, and the rainfall is low, averaging 20 to 30 inches in the year. Except in the coastal belt of young strata, where the soil is very fertile, vegetation is sparse or absent. This is due to the thin soil covering, continually washed off by heavy rains, to the dryness of the climate, to the destructive effects of the dense sulphurous fumes generated in the former method of heap-roasting, to the removal of timber in the past for mining and other purposes, and to the neglect of the community or the state to repair these losses. The chief trees are oaks, corks and olives, a local species of pine (*pina del pais*), some acacias, and the gum-cistus (*Eucalyptus globulus*). The last has been extensively planted around some of the mines. The soil over slates and porphyries is poor; but that from the weathering of the more calcareous diabases is much more fertile, and outcropping belts of these rocks are frequently marked by groves of corks and pines.

GEOLOGY.

I. STRATIGRAPHY.

The northern part of the area is composed of a belt of pre-Cambrian schists and gneisses, with Cambrian and Silurian strata (schists, phyllites and slates) lying still further north. To the south lie the rocks of the mining district—a uniform series of argillaceous schists and phyllites, with greywackes and thin-bedded slates, and occasional quartzites. The general strike of the series is east and west, while their dip is nearly always to the north, but variable in amount. The rocks were considered by Gonzalo y Tarin to belong to both the Silurian and the Carboniferous (Culm), and were so mapped by him. The existence of the Culm was determined by fossils which occur at various

points in the neighborhood of the Rio Tinto mines, and elsewhere. The following species have been described by Lucas Mallada:[1] *Goniatites sphæricus, Posidonomya becheri, P. gonzaloi, P. edmondia(?), P. constricta, P. barroisi* and others. Both Fraas and Etheridge, however, considered the Rio Tinto rocks to be of Devonian age[2] and Mallada has described Devonian rocks in the provinces of Badajoz and Cordoba.[3] Most workers, however, regard these rocks, characterized by *Posidonomya becheri,* as belonging to the Culm.

Gonzalo's identification of Silurian rocks in the mining zone rested partly on supposed lithological differences, and partly on the earlier researches of J. F. N. Delgado[4] in Portugal, and of Charles Barrois[5] in the Pyrenees, on some discoveries of nereites which were supposed to be fossils of Silurian age. These have been found in the slates at Santo Domingo, at Lagunazo near Tharsis and elsewhere,[6] and consequently a large portion of the sedimentaries in the area were mapped as Silurian.

Later researches, however, indicate that the nereites are much more probably worm trails or shell-fish burrows. Further, Delgado now regards the nereites-bearing rocks of Santo Domingo as Devonian.[7] Again, there is a total absence from

[1] "Descripcion (fisica, geologica, y minera) de la provincia de Huelva," Mem. Com. Map. Geol. Esp., Madrid, Vol. I., 1886, p. 663.

[2] J. H. Collins, *Quart. Journ. Geol. Soc.,* XLI., 1885, p. 246.

[3] "Explic. Map Geol. Esp.," *Bol. Com. Map. Geol. Esp.,* Madrad, III., 1898, p. 85.

[4] J. F. N. Delgado, "Breves apuntes sobre los terrenos paleozoicos de Portugal," *Revista Minera,* Madrid, XXI., 1870, p. 505; "Terrenos paleozoicos de Portugal," *Mem. Ac. Cienc. Lisb.,* ser. 2, V., pt. II., 1878; "Sobre a existencia de terreno siluriano no Baixo Alemtejo," Lisbon, 1876; "Relatorio da commissao desempenhada em Hespanha an 1878," Lisbon, 1879; "Correspondence relative à la classification des schistes siluriens à néreites decouverts dans le sud du Portugal," *Jorn. Sci. Math. Phys. Nat.,* Lisbon, VII., 1880, p. 103.

[5] Ch. Barrois, "Sur les ardoises à néreites de Bourg d' Oueil (Hte. Garonne)," *Ann. Soc. Géol. du Nord,* XI., 1884, p. 219.

[6] Gonzalo y Tarin, *loc. cit., sup.,* I., 1886, p. 395.

[7] J. F. N. Delgado and P. Choffat, "La carte géologique du Portugal," Congres. Géol. Internat., sess. VIII., 1900, Paris, 1901, p. 743; "Carta geologica do Portugal," Dirreçção des Trabalhos Geologicos, Lisbon, 1899; "Système silurique du Portugal," Commission du service geologique du Portugal, Lisbon, 1908, pp. 10, and 223.

these slates of the graptolites which occur in the Silurian rocks in the extreme north,[1] nor is there any recognizable unconformity in the series of rocks in the mineral zone. There is not sufficient lithological variation to support the hypothesis that the rocks are of more than one age. Lastly, the writer obtained a number of well-preserved specimens of *Posidonomya becheri* from slates at Cabezas del Pasto mine, west of Tharsis. These rocks were mapped by the Spanish commissions as Silurian, but they are obviously of the same age as those at Rio Tinto, which are mapped as Culm.

In conclusion, it may be stated that there is insufficient evidence for the existence of Silurian rocks in the mining district. The slates are probably all of one age, *i. e.*, lower Carboniferous, or possibly Devono-Carboniferous.

Of sedimentary formations younger than the Carboniferous, the only representatives in the district are a small patch of Triassic limestones, accompanied by an intrusive diabase, at Ayamonte at the mouth of the Guadiana; and rocks of Miocene, Pliocene and later age forming the southern coastal belt.

2. PETROLOGY.

The igneous rocks, which are very abundant in the area, are distributed in east and west belts parallel to the trend of the slates and older formations into which they have been intruded. They are divisible into three groups—a northern group of granites and allied plutonic rocks, a widespread series of porphyries and a group of basic dykes and sills. The area is, in short, characterized by a defined petrographic province, showing differentiation into a variety of rock types.

A. *Granites.*

These rocks occur as intrusive bosses and sheets to the north of the pyritic zone, and are also widely distributed in the adjoining provinces. They have been intruded into the ancient metamorphic rocks, and into all younger formations down to the Carboniferous. They are probably contemporaneous with the

[1] Gonzalo y Tarin, *loc. cit., sup.*, I., 1886, p. 405.

Hercynian disturbances, which were accompanied by plutonic intrusions throughout the rocks of the meseta.

The rocks of this group vary from muscovite- and biotite-granite, through intermediate types, to monzonite, tonalite and granodiorite. A hornblende granite is probably the most common type. The rock at Campo Frio, near Rio Tinto, is a granodiorite. A rock varying from hornblende-granite to granodiorite occurs immediately north of Concepcion mine, crossing the Odiel valley in a belt over a kilometer wide. It is intrusive into the adjacent Culm slates and also into an older diorite, and is itself penetrated by dykes of felsite and granophyre, and by still later dykes of diabase.

B. *Porphyries.*

The rocks of this group have a wide distribution both in the Culm series and in the older rocks to the north, where they are commonly associated with the plutonic rocks.

The nature and relations of these rocks have been much discussed. The majority of observers, including J. H. Collins (1885), J. Gonzalo y Tarin (1886), L. de Launay (1889) and J. H. L. Vogt (1899), have regarded them as intrusive. The highly cleaved and tuff-like rocks commonly associated with them were regarded by Collins as the result of contact metamorphism and of pressure during their intrusion, and by Gonzalo as representing zones of contact metamorphism; while Vogt considered that they were due to shearing or brecciation along the lines of junction of the slates and porphyries. F. Klockmann in 1894, and again in 1902, maintained that the rocks were lavas poured out during the deposition of the slates in Carboniferous times, and that the cleaved varieties were true pyroclastics subsequently more or less sheared. The results of the writer's work go to confirm entirely the conclusion of Vogt that the porphyries are intrusive sheets and sills, and that the "tuffs" of Klockmann are due to subsequent crushing and shearing along the margins of the intrusions. The facts on which these conclusions are based will appear below.

Massive Type.—The rocks are in general porphyries of various kinds. The more acid members are quartz-porphyry or rhyolite-porphyry (Fig. 29), containing abundant phenocrysts of quartz, and subordinate phenocrysts of orthoclase and albite. The feldspars are sometimes absent. The quartzes are sometimes in good crystals, and at other times rounded and corroded, with inclusions and inlets of the groundmass. Biotite, the usual

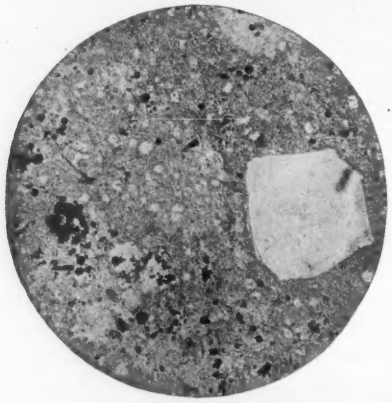

FIG. 29. Rhyolite-porphyry. Adjoining San Dionisio lode, Rio Tinto. The rock carries quartz phenocrysts and abundant smaller grains of quartz, embedded in a ground-mass of very fine felted sericite. It is impregnated with pyrite. × 36.

ferro-magnesian constituent, is subordinate, and generally quite altered. The groundmass is generally felsitic or crypto-crystalline. It is composed of feldspar microlites and quartz grains, and a common feature is the presence of abundant coarser granules of quartz. The rocks frequently tend towards granophyre, with micropegmatites of quartz and feldspar. These varieties are best described as granophyric quartz-porphyry (Fig. 30). Another variation is to quartz-keratophyre, in which the phenocrysts are of corroded quartz, abundant albite and some microcline, while the groundmass is microcrystalline and crowded with fine albite laths (Fig. 31). All these types are developed in the

two porphyry belts at Rio Tinto, but the predominant rock there is a rhyolite-porphyry or trachyte-porphyry. Eurite or granite-

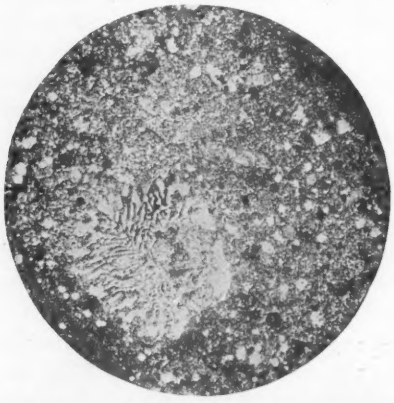

FIG. 30. Granophyric quartz-porphyry. Near smelting furnaces, Rio Tinto. A similar rock to the last, with frequent micropegmatites. In that illustrated, the felspar of the intergrowth has been completely sericitized.

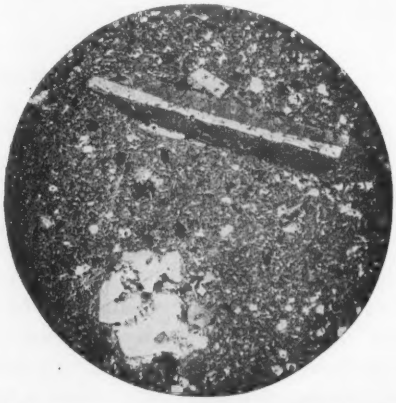

FIG. 31. Trachyte-porphyry near Keratophyre, Tharsis. The rock contains phenocrysts of orthoclase and albite, and of corroded quartz. The groundmass is felsitic and contains abundant fine felspar-laths and a good deal of coarser quartz. × 36.

aplite (orthoclase-quartz rock) occurs with rhyolite-porphyries at El Cerro and elsewhere, and a rock varying between granite-porphyry and monzonite-porphyry constitutes a prominent boss in the Odiel valley, between Sotiel and Santa Rosa. The less acid members carry no quartz phenocrysts, and do not show alkaline affinities. The groundmass is coarser and the rocks are markedly porphyritic. Orthophyre or trachyte-porphyry, syenite-porphyry and monzonite-porphyry are the characteristic types. Orthoclase occurs, but the chief phenocrysts are albite and oligoclase-andesine. Hornblende and biotite occur, but not in great quantity.

Subsequent dynamic metamorphism is generally marked in these rocks. Quartz phenocrysts are strained and frequently granulated, feldspars are broken or bent, and these latter, together with the groundmass, are often converted into aggregates of fine sericite fibers. Inclusions or inlets of the groundmass in quartz phenocrysts are at the same time frequently unaltered, owing to the protection thus afforded. Micrographic intergrowths show unaltered quartz and completely sericitized felspar. Abundant colorless epidote is also frequently developed in the felspar phenocrysts.

That the porphyries are intrusive in character is suggested in the first place by the occurrence of micropegmatites, and by the corrosion of quartz-phenocrysts; the latter is probably an intratelluric reaction. Owing to subsequent metamorphism of the slates, contact effects are not easily recognized. The porphyries, near their margins, however, frequently contain baked inclusions of slate, which are clearly distinguishable from brecciated fragments. Another common feature of the contact is the presence of a band of porcellanite three or four inches wide, on the margin of the porphyry. Microscopic examination of the contact zone shows, in some cases, that the original bedding planes of the slate, marked by layers of fine quartz grains, have been crossed by the line of junction of the porphyry, while a later cleavage, marked by the development of sericite folia in the slate, runs parallel with the line of junction. Lastly, there was observed, in the case of some wide masses of porphyry at Rio Tinto,

Sotiel and elsewhere, a distinct variation from a coarse texture in the center, to a finer-grained and less acid rock along the margins. These facts leave little doubt that the porphyries are intrusive.

Sheared Types.—The highly cleaved varieties are found sometimes as self-contained belts in the slates, but nearly always as marginal phases of the massive porphyries adjoining the slates. In the hand-specimen they are distinguished by a well-developed cleavage or foliation, by abundant quartz-grains, and by a silky sheen or luster. Under the microscope they show a foliated groundmass of sericite, most marked in the finer-grained rocks (Fig. 32). Abundant quartz-grains are scattered through the

FIG. 32. Intensely sheared (rhyolite) porphyry. Poderosa mine. Quartz phenocrysts are crushed and granulated, and the mass of the rock has been converted into fine sericite in which marked schistosity has been developed. The figure shows a large sericitized felspar crystal, which has been elongated at right angles to the pressure. × 36.

groundmass, showing, in the strain phenomena and granulation, in the corrosion inlets, and inclusions of less altered groundmass, complete identity with the quartz-phenocrysts of the massive rocks. Granulation of the quartz-phenocrysts is very common, the grains being recemented by secondary silicification. Micropegmatite growths are occasionally seen, while felspar pheno-

crysts are completely altered to sericite with some epidote. The different types of massive porphyry are invariably accompanied by their corresponding sheared margins, which show the closest affinities to the unaltered rock in each case. All the sheared types are invariably quite homogeneous over considerable widths of exposure, and contain no constituents foreign to themselves, while there is an absence of any rocks which can be classed as agglomerates or as volcanic breccias. Owing to the intense alteration, their identification is sometimes difficult, but an examination of over fifty specimens, collected from all parts of the area, has given no evidence of a fragmental or pyroclastic origin. They are concluded to be the result of crushing and shearing by earth pressure and movement along the margins of the porphyries, which were naturally lines of weakness. This conclusion is further supported by the fact that the adjoining slates are also converted into fine-grained sericite-schists.

Finally, considerable difficulty in accepting Professor Klockmann's view lies in the fact that the porphyries and their sheared associates are found, of similar types, in the older Palæozoic rocks to the north as well as in the pre-Cambrian metamorphic rocks, where they are associated with granites.

In point of age, the porphyries, from field association and petrographic analogy, clearly belong to the same stage of intrusion as the granites. Both series of rocks are, however, older than the chief earth-movements of Permo-Carboniferous time; the freedom of the granites from the effects of pressure and movement which have so markedly altered the porphyries being due to the greater resistance of the larger masses.

C. *Basic Dykes and Sills.*

These are likewise widely distributed, though less abundant than the porphyries. They are intrusive into all formations up to and including the Trias at Ayamonte. Hornblende-diorites and camptonites, with some kersantites, occur in the northern district, but those in the ore-bearing region are pyroxenic, and include diabases, augite-porphyrites, augite-diorites and dolerites. The ophitic habit is generally marked, and olivine is rare or

absent. A high titanium content, marked by ilmenite, pleochroic titaniferous augite and perovskite, is characteristic of the majority. The felspars are lath-shaped, and vary from andesine to anorthite. Brown hornblende is an occasional constituent, while apatite is common. Grains of pyrite and chalcopyrite are common, both in the rocks themselves, where they may be primary, and in the contact-altered slates. Contact action on the slates has resulted in the development, first of chlorite, and finally of abundant yellow epidote. The rocks are marked in the field by their spheroidal weathering and ferruginous clay, and by the more abundant vegetation which they frequently support.

The basic rocks, at least the pyrogenic group, whose members appear, from petrographic similarity, to be all of the same age, are clearly the youngest series of igneous rocks in the area, cutting not only Triassic strata, but also the granites and porphyries in certain places. They are further unaffected by the dynamic processes which have left their mark on the porphyries, and the epidotization of the contact zones has been superimposed on the earlier sericitization of the slates. The basic rocks have therefore been intruded near the end of the Hercynian tectonic epoch.

3. STRUCTURE.

Folds.—The rock formations throughout the area have a remarkably uniform strike, which varies but little from east and west, while the persistent northerly dip is another noteworthy feature. Both these phenomena are preserved in the associated igneous rocks. Local folds occur, but they are unimportant. The exact determination of the structure is rendered difficult by the absence of constant fossiliferous horizons or of beds with a persistent lithological character, which might serve as indicators. The general features, however, suggest a series of inclined isoclinal folds formed by uniform pressure acting against the old metamorphic complex in the north. This would account for the uniform and unchanging dip. Further, there is, as will be pointed out later, considerable evidence for shearing and overthrusting in the mineral zone. These effects, acting along the limbs of such inclined folds, may account for the apparent great

thickness of the slates. The constant alignment of all the igneous rocks, in sheets, sills, or bosses parallel with the strike of the slates, shows the effects of the earth pressure during the intrusions.

Cleavage.—Flow-cleavage, induced by a continuation of the pressure which folded the rocks, is well developed in the slates. As a rule, the cleavage planes, normal to the direction of pressure, are coincident with the bedding planes, and the same forces

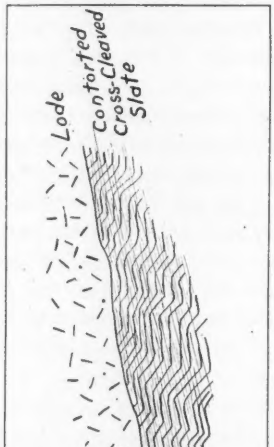

FIG. 33. Sketch in adit level west, Masa Grande, Sotiel, showing lode crossing bedding planes and parallel to cleavage of contorted slate.

have been responsible for the sheared and slatey structures along the margins of the porphyries. The development of abundant sericite has been the mineralogical effect of the process in both cases. It is noteworthy that the basic dykes and sills are uncleaved, and are therefore subsequent to these effects, though their immunity from cleavage may be, in part at least, due to their massive and resistant character, like the bands of greywacke and quartzite in the slates. At times the cleavage,

marked by sericite folia, is seen to be discordant to the bedding. In such cases the superinduced cleavage is generally found to be parallel to lode walls and to lines of junction of porphyry, while the bedding is intersected by these (Fig. 33).

Faults.—The whole of the mineral zone has been considerably affected by faulting, subsequent to the folding and cleavage. The fault planes are coincident with the bedding planes of the slates, and are for the most part shear zones or slip planes which have been gradually developed. Brecciated zones and intense crushing are occasionally seen, as along the lines of junction of slate and porphyry, and in other planes of weakness. Further, the lode-zones are, in practically every case, zones of former movement, expressed sometimes by brecciation, but more usually by gentle shearing. That these effects are later than the development of cleavage is shown by the fact that the rock fragments in brecciated zones are composed of previously cleaved and sericitized slate and porphyry. The fault movements are also later than the basic intrusions, for a zone of brecciation along the lode walls at Santo Domingo has involved a diabase on the south wall of the lode. It is quite probable that many of these later movements consisted in overthrusting along the limbs of inclined or reversed folds, but the evidence on this point is not very definite. The disposition and form of the ore bodies, however, suggests that very considerable displacements have taken place along what are now the lode walls, accompanied possibly by the formation of large slip cavities. There is, however, not generally any intense contortion or crushing of the slates, and the movements must have been very gradual.

4. HISTORY.

The sequence of events in the area during the critical epoch (Hercynian) may be summarized as follows:

1. Uplift and folding of the Culm slates, accompanied by intrusions of granites and porphyries. The folding forces acted towards the north against the buttress of ancient crystalline rocks, and the igneous intrusions, resulting from sub-crustal pressure, came near the beginning of the movements.

2. Continuation of the pressure after the development of folding resulted in cleavage.

3. A period of tranquillity succeeded, accompanied possibly by subsidence, until the Triassic.

4. A resuscitation of the forces caused reëlevation, with the intrusion of basic sills and dykes, the result of further magma differentiation during the intervening stage. This was again followed by movement which gave rise to extensive shearing and overthrusting, and the disturbing forces were finally dissipated.

5. The last event in the series was the formation of the pyritic ore bodies, probably concentrated in the first place by gradual magma differentiation connected with the successive intrusions, and finally deposited along the zones of shearing and movement.

(*To be continued.*)

THE ALEXO NICKEL DEPOSIT.

A. P. Coleman.

The Alexo nickel deposit, in Dundonald and Clergue townships, near Matheson in northern Ontario, is of special interest as presenting a type of magmatic segregation of sulphides new to Ontario. It consists mainly of pyrrhotite and chalcopyrite segregated at one side of an area of serpentine. The general geology of the region is not very well disclosed since most of the region is drift-covered.

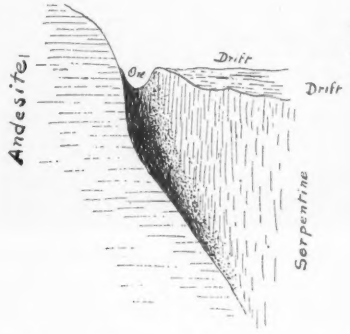

Fig. 34. Section of Alexo Mine. A. P. Coleman. Scale 100 ft. = 1 inch.

The deposit occurs on the north side of a small group of hills consisting of altered andesite, once a lava, as shown by the pillow structure here and there to be seen.

The ore was found at the foot of the outcrop of andesite and has been slightly opened up by two test pits. The underground relationships have been disclosed by a number of diamond drill holes.

The ore and serpentine lie against the andesite as a foot wall and have a dip varying from 45° to 60° to the north.

Owing to its relative softness the serpentine has been cut down by weathering to a much lower level than the andesite and is mostly drift-covered.

At the test pit showing the best outcrop ten feet of solid ore rest against the andesite, followed by twelve feet of mixed ore and rock, which may be called pyrrhotite-serpentine, and finally by serpentine nearly free from ore. The boundaries of the three phases blend into one another.

Below the surface the solid ore thins out and is not found in

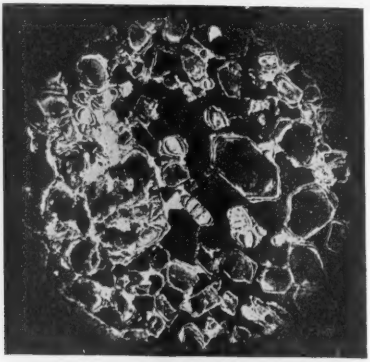

FIG. 35. Section of pyrrhotite-serpentine. Pseudomorphs after olivine in ore.

diamond drill cores from 100 feet depth, where only rock spotted with ore occurs.

Thin sections of the serpentine show excellently preserved forms of olivine, which in most cases make up practically the whole of the rock; though in one section a little augite occurs, and in another some carbonate, which may not have originated from olivine. Between the crowded crystals there is a little rather turbid serpentine of a different character, showing a very slight change of light and shade when rotated between crossed nicols. This may have been a very basic glass originally. With the serpentine there is the usual amount of magnetite, representing the excess of iron in the olivine.

The pyrrhotite-serpentine rock proves exceedingly interesting. There is every gradation from ore with a few well-formed crystals of olivine (now transformed to serpentine) floating in it, to serpentine with a small amount of ore replacing the turbid matrix between the crystals.

The olivine forms are often as sharp as models with no suggestion of rounded angles or of etched surfaces.

On the ore dump near the best pit one sees that some fracturing and slickensiding has taken place, perhaps due to expansion in the transformation of olivine into serpentine. Along the tiny fractures thus produced chrysotile has been deposited, asbestos of prime quality except for shortness of fiber.

The ores consist to the eye of pyrrhotite, some "white" iron pyrites, and chalcopyrite, the latter tending to accumulate along the foot wall or near pieces of enclosed rock. Whether pentlandite occurs intimately mixed with the pyrrhotite or not has not been determined, but the ore runs as high in nickel as in good mines of the Sudbury region, a specimen assaying 5.79 per cent. of that metal. The general appearance of the ore and the arrangement of the ore body suggest strongly the marginal deposits of the Sudbury nickel range. There is every reason to suppose that the Alexo deposit has accumulated in the lower part of a bay-like curve of the country rock while the magma was still molten, as has been proved to be the case with the Sudbury marginal mines.

The region is largely drift-covered, so that the mass of serpentine could not be traced even a short distance north to see if further differentiation into more acid rock than peridotite has taken place. For complete parallelism with the Sudbury norite this should be the case.

No similar association of pyrrhotite with an ulta basic rock is known in Ontario, but something quite like it is described by E. S. Bastin from Maine, where small outcrops of peridotite show an intimate mixture of pyrrhotite, though no solid ore is mentioned. The pyrrhotite in the Maine deposit is considered to be of magmatic origin and contemporaneous with the other con-

stituents of the rock,[1] according with the conclusions reached in the study of the Alexo deposit. The analogy of the Alexo ore body with the marginal type of nickel deposit in the Sudbury region is close; though here an exceedingly basic rock is the ore bearer instead of the rather acid norite of the great Sudbury sheet.

The Alexo mine was examined for the Canadian Copper Company, and it is through their courtesy that this note on its geology is published.

[1] *Jour. Geol.*, Vol. XVI., No. 2, pp. 124–136.

THE FLUORSPAR, LEAD AND ZINC DEPOSITS OF WESTERN KENTUCKY.

F. JULIUS FOHS.

These deposits are of economic interest because fluorspar occurs more extensively than elsewhere in the United States, and has zinc, lead and barytes associated; scientifically, they are of interest because of their occurrence in fault fissures and the association of basic dikes, differing in these particulars from the other lead and zinc deposits of the Mississippi Valley.

The regions in which these deposits occur is eighty miles long and fifty miles broad; the Tennessee River lies to the west and the Western Kentucky coal field to the east. It comprises Caldwell, Crittenden, Livingston, Christian, Lyon and Trigg counties, the developments being largely confined to the first three. Hardin, Pope and Salme counties in Illinois and just north of the Ohio River form a continuation of the same mining district.

The topography of the region is mature. The elevations range from 300 feet in the river bottoms to 750 feet at the top of the ridges. The limestone valleys average around 440 feet, the sandstone uplands about 110 feet higher. These counties form the extreme west portion of the interior lowland of the Allegheny Plateau, since to the west of the Tennessee River the Gulf Plains province sets in and north of the Ohio River is the eastern extension of the Ozark Plateau.

STRATIGRAPHY.

The geologic section presented by the region is the following:

Recent: Alluvial	0–40
Quaternary (Pleistocene).	
Columbia formation (Brown loam and clays)	0–25
Lafayette formation (Stratified drift)	25–140

Carboniferous System.	
Pennsylvania Series.	
Allegheny formation (Lower Coal Measures)	60–100
Pottsville formation (Conglomerate sandstone)	80–180
Missippian Series.	
Chester Stage.	
Lockhart limestone (Shales and some sandstone)	100–175
Birdville formation (Sandstone, shales and limestones	315–630
Tribune limestone	100–150
Cypress sandstone (Includes a limestone)	60–150
Ste. Genevieve limestone.	
Ohara limestone	31–121
Rosiclare sandstone	1–25
Fredonia (oölitic) limestone	115–150
St. Louis limestone	300–500
Tullahoma formation (Under cover in western Kentucky)	200–225
Devonian System.	
Ohio shale (Under cover in western Kentucky)	45–100

The Mississippian rocks cover most of the district, the Pennsylvanian rocks being confined to the east edge of the district and a few scattered fault blocks. The Quaternary clays and gravels are prominent chiefly west of the Cumberland River. This, together with the alluvial and a thin residual mantle, cover all traces of the veins where present.

The sandstones in proximity to the veins have been altered by the mineralizing solutions to quartzite sometimes for a distance of almost 200 feet from the vein.

Owing to faulting and subsequent erosion, anywhere from a few feet to more than fifteen hundred feet of the upper strata have disappeared in various parts of the district, leaving a checker work of unlike contiguous blocks of strata.

IGNEOUS AND METAMORPHIC ROCKS.

The Appalachian petrographic province of Tertiary age is characterized by extremely basic dikes. The main belt is 2,000 miles long and 20 miles wide and extends from Nova Scotia to Alabama. Outliers from this belt found in Elliott County in eastern Kentucky, in the counties under consideration in western

Kentucky and southern Illinois, and in southeastern Arkansas, indicate a consanguineous magma 1,000 miles broad.

In western Kentucky and southern Illinois dikes and sills of mica-paridotite and pyroxene-lamprophyre have been intruded. Mica-peridotite occurs on both sides of the Ohio River, while the pyroxene-lamprophyre has been found in Illinois only. The former is characterized by olivene, the latter by a colorless augite. The mica common to both is largely phlogopite and occurs in phenocrysts or laths in a dark green compact groundmass. The rocks run 34 per cent. silica, which indicates their extreme basicity. Little or no feldspar occurs in them; apatite, magnetite, ilmenite and perofskite are among the accessory minerals.

The rock, for the most part, is found greatly altered. It weathers to a soft green and finally to a golden-yellow micaceous clay. Serpentine, cysotite, calcite, pyrite, etc., are chief among the alteration products.

The dikes, with one or two exceptions, strike northwest. Two or three parallel dikes may occur, forming a zone one to two miles wide and several miles long. The maximum width noted of an individual dike was 15 feet, while sills up to 6 feet thick have been found. Fifteen or more dikes have been discovered. Rarely are the walls of the dikes faulted; when they are, they have been faulted after the intrusion of the dikes. Fault zones occur paralleling and crossing the dikes.

There is little evidence of contact metamorphism. Occasionally the limestone wall has been partly changed to white fine-grained marble, sometimes tinged green—rarely with mica phenocrysts developed. Sometimes the sandstones have been changed to quartzite; when this change has taken place, it is most likely that such quartzites have been formed as those previously described.

STRUCTURE.

The general structure of the district is such as to suggest the crossing of two monoclines, one with a northwest, the other with a northeast strike, forming a fan-fold, the upraised limb to the

northeast (coinciding with the Rough Creek Uplift, which crosses the river near Shawneetown, Illinois, and is a well-marked structural feature eastward through Kentucky), the depressed limb to the west and south. This strained condition of the strata was supplemented by local domes due to local magmatic expansion, making facile the intrusion of the dikes. Subsequently came extensive faulting.

The faults are of two types, normal and shift. Only two reverse faults have been found. Normal faults are preponderant and border the fault blocks. Shift faults (usually shear zones) are found within the fault blocks parallel to the normal faults and within a mile of them; the shift faults are doubtless the result of adjustment strains. Simple faults are rare. The faults are found grouped in parallels, *en echelon*, and simultaneously intersecting sets with parallel and diverse displacements forming zones up to a mile wide and thirty miles long.

The fact that a majority of the faults and fissures constitute members of simultaneous intersecting sets is helpful in locating and prospecting the faults. Since they are tension fractures they make angles of 30° with one another, seldom varying more than 5° from this. Hence, if the strike of any single joint or fracture is known the others of the set are easily determined. Often only two members of a set are obtained, sometimes a third, and less often a fourth one. Prospecting to cut intersecting veins may be done best at an angle of 30° from the known fissure.

Individual faults usually have a length of one quarter to one half mile, but are to be found exceeding a mile long. The maximum displacement noted was 1,400 feet; faults of 500 to 600 feet displacement are common, while the majority have as much as 200 feet. The depth will vary from one thousand to two thousand feet; in some cases it will exceed this. The general strike of the faults is northeast, with a second set paralleling the dikes, that is striking northwest. The average dip is about 75 degrees. The number of faults and fractures in the district is very great, as will be appreciated when the bulletin now in press

is issued with its forty detailed maps of the more broken parts of the district.

ORE AND SPAR DEPOSITS.

Fluorspar is the principal mineral mined. Calcite is next in abundance but is not saved. Barytes occurs locally in notable amount and in some of the minor veins is intergrown with the fluorspar. However, the greater part of the veins are practically free of this mineral. Zinc blende occurs in varying amounts in parts of the veins, sometimes 5 to 10 per cent., but in some instances 15 to 20 per cent. Above water level it is often altered to smithsonite, of which considerable quantities have been mined at a few points. Galena seldom makes up more than 3 per cent. of the ore.

The following is a list of the other minerals associated to a greater or less degree, but not of economic value: Ankerite, bitumen, calamine, cerussite, chalcopyrite, copper, greenockite, hydrozincite, limonite, malachite, marcasite, pyrite, pyromorphite, quartz, sulphur, stibnite and cobalt—nickel-bearing wad.

There were three distinct depositions with fluorite, barite and calcite the predominant mineral in the order given. Metallic sulphides were associated with each as were small amounts of the other two.

For the metalliferous minerals the general order of deposition in the fluorite, barite or calcite was as follows: pyrite, chalcopyrite (both only in minute amounts and of occasional occurrence), galena and zinc blende. The two last named are found of later deposition also, being deposited in open spaces or along sheeting planes in the fluorite, barite or calcite.

Fluorite and barite occur intergrown usually, the former in the latter; calcite and fluorite, and calcite and barite, the calcite also usually in the fluorite or barite. Galena has been seen only in one instance with barite, the barite then coating the galena crystals. Fluorite of two or more generations may be found in a single crystal, often of different colors.

Fissure fillings, cemented breccias and replacement deposits

occur separately or combined in a single deposit. Fissure fillings occur carrying fluorspar alone or with barite or calcite intergrown. More rarely there are compound banded veins of which the following is a good example: (1) fluorite, (2) barite, (3) barite, (4) zinc blende, (3) barite, (2) barite, (1) fluorite. This was seen at the Lowery mine at a depth of 15 feet, the vein reaching a maximum width of 3 feet between walls of Ste. Genevieve limestone.

Ordinary breccias are common to the normal fault fissures and sheeting breccias to shift fault shear zones. Breccias are common in compact limestone, chert and quartzite; occasionally, calcite breccias occur as at the Columbia mine. The breccias occur cemented by all the principal minerals. The best example of a sheeting breccia was that of a compact buff limestone at the Burns 3-acres mine. The limestone there has parallel seams and cross-seams cemented with purple fluorspar or zinc blende or both.

All the principal minerals occur replacing either vertically sheeted or thinly laminated beds of quartzite or limestone except barite which replaces limestone only and rarely. Calcite is found replacing limestone sheets 1 to 12 feet wide on either side of a regular deposit. Fluorspar occurs replacing quartzite for a width of 20 feet at the Susie Beeler mine. Where fluorspar replaces limestone, metasomatic quartz hexahedrons are commonly associated which form what Spurr has termed jasperoid. At the Parish mine, fluorspar replaces laminated limestone beds for a thickness of 50 feet; in such instances fluorspar alternates with jasperoid, forming a beautiful ribbon structure with fluorspar crystals comb-in-comb between the jasperoid layers. Fluorspar, jasperoid, zinc blende and galena replace a sheeted zone of oolitic limestone over 19 feet wide at the Evening Star mine, running 5 to 10 per cent. galena and 15 to 20 per cent. zinc blende. Another example where zinc and lead predominate is the following section from the 135-foot level of the Columbia mine: Birdsville shale forming west wall; zinc blende disseminated in limestone, 2 feet; galena and zinc blende disseminated

in calcite, 2 feet; finely-grained zinc blende with coarser galena replacing and grading irregularly into Ste. Genevieve limestone wall, about 2½ feet.

A typical section illustrative of a mixed type of deposit, fissure filling, breccia and replacement in one is the following from the 70-foot level of the Memphis incline: Ste. Genevieve limestone calcite-seamed forming the foot wall; massive granular white fluorspar, 8 feet 2 inches; calcite-limestone breccia, 1 foot; Ste. Genevieve limestone hanging-wall replaced to a small extent by finely-grained zinc blende.

The largest ore and spar bodies are found in the locally more fractured parts of the district and where the wall rocks are suitable to deposition. The deposits extend practically to the surface in all cases, there being a covering of usually less than 15 feet and in extreme cases up to 40 feet of surface débris. Difference in elevation only affects the deposits in that those above water level have been subjected to weathering. The deposits will extend to a depth greater than it will be profitable at present to mine them, some of them, perhaps, to a depth of 2,000 feet. The character of the mineral differs not only frequently in the cross and approximately parallel veins but often for a short distance along a vein. Changes in depth depend both on change of wall rock and of associated conditions. There is no evidence of decrease of fluorspar in depth. The greatest depth reached in any of the veins is now over 500 feet; at this depth the vein is 20 feet wide. Some of the veins are barren. Along the veins, pinches and swells occur, and the shoots reach a width of 30 feet or more, though the average vein is four feet or more. The length of the shoots varies greatly. (A recent study of the size of the shoots and their relation to wall rock, etc., of all the veins in western Kentucky and southern Illinois has brought out some interesting points; these will be brought out in a forthcoming paper.)

Genesis of the Deposits.—Fuorspar being the predominant mineral may be taken as an index to the type of deposit. Fluorspar, in general, is associated with three genetic types:

(1) Pneumatolytic, (2) pneumato-aqueous and (3) thermo-aqueous deposit, which correspond to three mineralogical types—(1) tin, (2) gold-telluride, and (3) spathic lead-zinc deposits. The occurrence of these types increases from first to third, the spathic lead-zinc deposits being several times as abundant as the other two. The western Kentucky deposits belong to the third class.

The wall rocks of the district form an accessible source of calcium for the fluorspar, but do not carry appreciable fluorine. The dike rocks carrying, as they do, phlogopite and apatite, two fluorine-bearing minerals, suggest the parent magma as the likely source of the fluorine, the fluorine being brought up in thermal solutions as an after effect of the eruption. It was probably brought up in the form of silicofluorides of lead, zinc, copper, calcium, barium, etc. (salts of $H_2SiF_6Aq.$), as first suggested by Dr. H. Foster Bain. Carbonic acid and hydrogen sulphide were also brought up and entered into the processes involved in precipitation of the minerals. The carbonic acid dissolved the limestone of the walls, forming calcium bicarbonate. The silicofluorides were decomposed by the calcium bicarbonate, while hydrogen sulphide assisted in the precipitation. These reactions resulted in the formation of calcium fluoride, silica, a metallic sulphide or barium sulphate, carbonic acid, and hydrocarbons, also calcium carbonate. The silica in some instances replaced the limestone in conjunction with the fluorite, forming jasperoid-fluorite or where sandstone formed one wall the silica was deposited separately from the fluorite, in between the grains of the sandstone (probably best explained by attraction due to mass action) forming quartzite. The excess of carbonic acid formed acted to dissolve more limestone, and when the solutions were no longer saturated with sufficient silicofluoride to precipitate fluorspar the solution would become supersaturated with calcium carbonate which precipitated as calcite. This probably explains the formation of the large calcite bands replacing the walls. The excess of hydrocarbons together with the organic hydrocarbons resulting from the dissolved wall rock accounts for the

hydrocarbons in the fluorspar, the oxidation of some of which are responsible for its colors. The fluorescence of some fluorites is no doubt due to the presence in such fluorites of coloring hydrocarbons which are fluorescent. So far as known, none of the western Kentucky fluorite shows fluorescence.

Nothing definite is known as to the age of the deposits, but they are probably of Tertiary age.

Secondary Deposits.—The important alteration products are gravel, fluorspar, zinc carbonate and firesand.

The gravel fluorspar is the result of disintegration of the massive granular fluorspar, surface solutions depositing iron, clay and silica between the grains spreading them apart. The gravel deposits are usually of greater width than the vein from which they are derived for they represent the accumulation of perhaps a considerable height of eroded vein.

In those parts of the district where there has been much erosion of veins in which zinc occurred in adequate amount, the zinc has been reconcentrated along fissures, either replacing the wall rock as boulders in clay or a massive filling. Below water level it has been deposited as sulphide, above as carbonate in these concentrations. Some good sized deposits of this type have been mined, notably at the Old Jim, Old Dad, and Mann mines.

As the result of fault attrition and of chemical disintegration jointly, deposits of firesand have formed along faults which have Chester quartzite and St. Louis chert walls. The firesand is of excellent quality.

CONCLUSIONS.

The great number of faults and fissures in the district, the majority of which carry workable shoots to a depth of at least 1,000 feet, make certain a large possible tonnage of fluorspar—enough to supply all likely American demand for at least six centuries to come. Locally, the fissures carry barytes shoots; but compared with fluorspar shoots they are small in number, though at times of great width (20 feet or more). The by-product lead and zinc is often sufficient to add materially to the

profits, while in some veins, shoots in which lead and zinc predominate would pay to operate on their own account. The Sanders flotation process makes possible the separation of fluorspar from zinc blende; a custom mill would be able to operate profitably on such ores. The district lacks adequate transportation facilities and suffers from freight rate discrimination.

The foregoing is a brief summary of the detailed work which the writer has done in the district and which is fully covered in two bulletins prepared for the Kentucky Geological Survey, one of which, Bull. 9, "Kentucky Fluorspar Deposits," was recently reviewed in this journal, and the other, "Lead, Zinc and Spar Deposits of Western Kentucky," covering the geology, mine descriptions, etc., together with detailed maps, is still in the hands of the printer.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

CRITERIA OF DOWNWARD SULPHIDE ENRICHMENT.

DISCUSSION OF PAPER BY F. L. RANSOME.

Sir: The reading of this paper from a chemical point of view has proved both interesting and suggestive. Mr. Ransome shows very clearly what kinds of data are needed as criteria where questions of secondary enrichment are at issue, and how to use them; but in many places he also shows the defectiveness of our present data, especially the chemico-mineralogical data.

One point in connection with the chemistry of secondary enrichment has not, I believe, been properly emphasized. The sulphides of iron, especially pyrite and marcasite, occupy a unique place in this process, not only because certain ferric salts dissolve silver and gold, but because they are altogether the commonest representatives of a class of sulphides which on oxidation yield *sulphuric acid* as well as the sulphate of the metal. This free acid is active in several ways. In the first place, it dissolves other sulphides, such as zinc and lead sulphides, which happen to be present, forming sulphates and hydrogen sulphide. Buehler and Gottschalk[1] recently noted that the sulphides of zinc and lead oxidize much faster in the presence of pyrite or marcasite. The process may perhaps be so slow that the hydrogen sulphide

[1] This journal, V., 28, 1910.

is oxidized as fast as formed, but it seems to me that the explanation of their results is contained in the chemical action of the free sulphuric acid.

Again, when the descending oxidized solutions reach a level where sulphides are present and *air is not,* the free acid aids in the deposition (secondary enrichment) by dissolving those sulphides which are most readily decomposed and freeing hydrogen sulphide which precipitates the metals in the solutions which are most readily reduced, *e. g.,* copper, silver and gold.

Mr. Ransome has indicated how chemistry and mineralogy may be applied to the determination of temperature limits within which deposition has taken place. The application of mineral inversions or transformations in the solid state which occur at definite temperatures, to the estimation of temperature has already begun in geology. According as the internal structure does or does not correspond to the outward or crystal form, we judge whether a mineral has formed above or below the inversion point. The inversion in quartz at 570° promises to be especially useful in this way, and minerals with lower inversion points will prove still more valuable in the study of ore deposition. In a similar way the presence of *unstable mineral forms* may be used as temperature indicators. Here we have some *maximum temperature* above which the form can not exist and consequently could not have been formed. Thus marcasite is an unstable form changing to pyrite as low as 450° and must be formed in nature below that temperature. Foote states that aragonite begins to change to calcite at 57°.[1]

There is still another method which may be used to determine formation temperatures in geology. Certain reversible reactions, under definite conditions, run in one direction or the other above or below a certain point. Van't Hoff has employed this method in the study of the oceanic salt deposits. The most promising minerals, from this point of view, in the study of ore bodies, are the complex sulphides of which proustite and pyrargyrite are types. We expect to investigate this subject in due time in this laboratory. While minerals which exhibit polymor-

[1] *Z. phys. Chem.,* 33, 740, 1900.

phism will probably prove most helpful in deciding questions of temperature, we have in *all* minerals various *crystal forms of the same degree of symmetry* which in many instances must carry clues to their history. Some of these will perhaps be found to persist under more than one set of conditions, but others doubtless develop only under limited conditions such as more or less definite temperature intervals. Some geologists judge, as a result of field observations, that octahedra of pyrite are formed only at comparatively high temperatures, while the cube may be formed over a long range of temperature. The *composition* of the *solutions* out of which crystals come often has a determining influence on the crystal form. It is a well-known fact that where a substance possesses an unstable form, the latter will regularly crystallize from certain solvents. Aragonite has been observed to crystallize from spring waters which contain magnesium sulphate and it has also been obtained in the laboratory from solutions to which magnesium sulphate had been added. Thus by an adequate study of the influence which certain solutions exercise on the crystal form of minerals and on the genesis of unstable forms, we may in time arrive at the composition of solutions which have been active in the formation of natural deposits. Finally, inferences from the observed *paragenesis* of minerals may probably be carried much farther than they have been heretofore. If a number of different conditions may have prevailed in the formation of each mineral in a vein, the conditions which are common to each group and which may have prevailed when precipitation took place, will be much narrowed down.

In this discussion the attempt has been made to point out lines of work in synthetic mineralogy which may contribute further to the solution of these questions of secondary enrichment, viz., the search for vein minerals with low inversion points, the study of the conditions which give rise to unstable forms like aragonite and marcasite and the temperatures above which they can not exist, also the study of the relations which exist between conditions of formation and the appearance of crystal forms of the same symmetry. Such investigations in order to serve their

true purpose must be supplemented by no less painstaking observations on the paragenesis of minerals and their relation to geological conditions.

These methods will prove slow and often tedious, but they are full of encouragement to all who believe in sure relations between cause and effect in natural phenomena.

E. T. ALLEN.

Sir: Mr. Ransome gives a very useful summary of our knowledge of downward enrichment; as he himself points out, his article contains but little strictly original matter, so that the scope of the discussion upon his paper is necessarily somewhat limited.

Whilst in general accord with the criteria that he has laid down for demonstrating enrichment, it is worth while pointing out that in the discussion of the geological proofs of enrichment, he has omitted one piece of evidence, which though in a sense negative, is yet of extreme value, namely, the absence of change in the country rock. If, for example, I describe a vein of argentiferous galena, which shows the usual gossan carrying carbonate and sulphate of lead, comparatively rich in silver, succeeded by a zone of galena, poorer in silver, below which we find the vein very nearly barren or certainly not payable as far as either lead or silver is concerned, I appear to be describing a well marked case of secondary sulphide enrichment. If, however, I add that this vein occurs in the Mountain Limestone formation of the north of England, outcropping say at the top of the Great Limestone, and that the change from a payable lead-bearing vein to a practically barren one, coincides with the passage of the vein out of limestone country into sandstones or shales, it will be quite obvious that the change in the contents of the vein is due to the change in the country rock, and is in no way caused by secondary enrichment. Among the geological criteria of secondary enrichment, the author should therefore include evidence that the change in the nature of the deposit is unaccompanied by any corresponding alteration in the character of the country rock.

HENRY LOUIS.

REVIEWS

The Paleozoic Coalfields of Holland. The Deeper Geology of the Netherlands and Adjacent Regions, with Special Reference to the Latest Borings in the Netherlands, Belgium and Westphalia. By W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT, MR.JUR., F.G.S., Director of the service; with contributions on the Fossil Flora by DR. W. JONGMANS, Principal Assistant at the Herbarium at Leiden. Mem. Gov. Inst. Geol. Expl. Netherlands, No. 2, The Hague, 1909. 437 pp., with plates, maps, etc.

As suggested by the title of this memoir the Paleozoic coalfields of the Netherlands are essentially subterranean. They are a part of the Carboniferous basin of western Europe extending from the British Islands beneath the British Channel, the North Sea and across Belgium and Holland into the German Empire. The country is so deeply mantled with diluvium and alluvium that Carboniferous rocks nowhere reach the surface except at a few points near the southern frontier and in the deeper valleys along the southeastern border, mainly in South Limburg, where they constitute islands in the surficial deposits. Naturally, therefore, the investigation and exploration of the coal fields is mainly a matter of deep boring. The report consists largely of the detailed accounts of the logs and a comparative study of the numerous terranes encountered.

This old basin was more or less folded and repeatedly faulted as well as much eroded prior to the deposition of the later formations. The general trend of the folds is west-east to northwest-southeast. Earth movements affecting the coal series have progressed more actively during mid-Carboniferous, mid-Coal Measures, and post-Coal Measures times. The structure is especially complicated by faulting, which was vigorous in the middle Permian and which recurred in the Miocene, the Pliocene, and even the late Pleistocene. The effect of the dominant movements is the development of more or less distinctly east-west blocks. As already mentioned, the surface geology gives practically no clew to the underground geology, though in some cases, due largely to the late date of faulting or folding, the topography has been successfully utilized as a guide in selecting locations for boring.

Up to the time of publication of this report the explorations had resulted in demonstrating the continuity and general character of the lately discovered Campine coal field from its western development, south of

Antwerp in Belgium, across the rather narrow Dutch strip to the district of Aix-la-Chapelle, within the German frontier. Also, two other fields have been discovered to the northward of this. The first of these, called the Peel area, includes Helenaveen, and extends southeastward across the Dutch frontier to a point some distance beyond Erkelenz, in Germany. This area is supposed to be continuous at the east with a westward extension of the coal field of Westphalia which appears to stretch in a broad bend from the Rhine westward across the Maas, thus offering encouragement for exploration in a more northern area of the province of Limburg. Another region of exploration lies in the eastern portion of the province of Guelderland. On account of the deepening cover the drill has not yet reached productive coal measures in this district although the borings (which have disclosed the Zechstein) appear to offer distinct encouragement for continued exploration. To the northwest and north of these areas the Carboniferous lies, so far as known, too deep to justify exploration at the present time.

In view of the growing interest in our governmental policy as to tenure and development of coal lands it is interesting to read that "to prevent all disturbing competition a bill was passed by the legislature, conferring the monopoly of exploration on the state, without prejudice, however, to the subsequent exploitation of any discoveries which might be made by the service. When once a more definite knowledge shall have been obtained about the presumable coal reserves, it will be settled by parliament whether the mines are to be worked by private enterprise or by the state, or are to be divided between these two. It will then be possible to plot out the various concessions in the most practical manner, as to size and shape."

Although the German government carries its explorations to the depth of 1,400 meters, it appears to be the view of the Dutch Survey that coals below the depth of 1,200 or 1,250 meters are in general not to be regarded as commercially available. On account not only of the varying character of the intervening beds, which may, locally, include Tertiary, Cretaceous, Triassic and Zechstein sediments to be penetrated, but also of the faulted condition of the region, the problems of mining are often serious. Frequently thick deposits of salt are traversed in the Triassic and the Permian. Probably there are many American geologists, even among those interested in coal exploitation, who are unaware that several deep coal mines are in active operation in Holland at the present time.

The report is accompanied by a number of detailed maps showing the locations of the sections, and in many cases graphically indicating the character and thickness of the various formations traversed. Detailed descriptions of all the official and many unofficial borings are included in the text.

In most of the governmental bore-holes in which the Carboniferous was found (many failed to reach it) the depth to the latter was not less than 600 meters. For comparison the geologists note that in Westphalia, within the German area, the first coal seam was encountered at depths of over 900 meters in 141 borings; 1,000 meters in 70 borings; 1,100 meters in 40 borings; 1,200 meters in 5 borings, and 1,300 meters in 2 borings.

The drill records are discussed at great length and compared both paleobotanically and stratigraphically with the Upper Carboniferous sections of Great Britain, Belgium and western Germany. Dr. Jongmans contributes not only lists of fossil plants from a considerable number of borings, but also a most valuable comparative analysis of these floras with reference to their range in other areas. The result of these comarisons is to show very plainly that in the Campine and other fields to the north in Holland we have lower groups of the Coal Measures corresponding closely to the development in the southern basins of England. In fact, the discussion of the paleogeography of the northwestern European coal trough, of which these folds formed a part, constitutes an interesting section of Van der Gracht's report. All of the productive coals of South Limburg are correlated with the Middle Coal Measures in the British area though it appears probable that a slight thickness of the overlying "transition series" also has been passed through. The representative of the British Lower Coal Measures (Middle Pottsville or older) does not seem to be defined with entire clearness, especially with regard to the lower limit. The Dutch geologists regard the deposition and formation of coals as having been continuous from the Lower Carboniferous into the Upper Carboniferous in several regions of the great original basin. The economically valuable group in Holland (Middle Coal Measures) appears to the reviewer to correspond approximately, according to the fossil plants, to our Kanawha series—*i. e.*, Upper Pottsville—in the Appalachian trough.

The Middle Coal Measures in Holland are rich in coal. The coals are numerous and frequently thick, several of them exceeding eight feet in thickness, while nearly every core which penetrated to any considerable distance the coal-bearing series reveals two to five coals a meter or more in thickness. In many of the borings the proportion of coal with reference to the thickness of the formation penetrated averages considerably over three per cent., nearly three per cent. being regarded as of "workable thickness." In the South Limburg basin the coals vary in character from anthracitic, with 95.2 fixed carbon (ash- and moisture-free) to 60 per cent. of fixed carbon, thus embracing steam, gas and coking, as well as semi-bituminous, grades. The report is deficient in information regarding the ash content, probably on account of the difficulty in procuring clean samples from the borings. Where the ash is

reported, as in several mine examples, it is very low, mostly under 5 per cent. The volatile content is given in figures obtained both by the German (Bochumer) method, in which the heating is broken off immediately on cessation of the flame from the crucible, and by the Belgium method, in which heating is continued for one minute after cessation of the flame. The percentage of volatile constituents is found in general to decrease in passing from the higher to the lower coals, thus conforming to the law observed to obtain in other European coal fields as well as in the United States. The reviewer is further interested in noting evidence of progressive regional devolatilization. This varies somewhat in different districts, often, perhaps, as the result of the influence of folding and faulting. In general, however, there is an advance in the devolatilization as one traverses the basins from north to south; that is, toward the region of maximum pressure. The enormous stresses to which this region has been subjected are conspicuously shown by the tremendous northward thrusts, among which the Eifelian fault is classic. DAVID WHITE.

From Prospect to Mine. By ETIENNE A. RITTER. Mining Science Publishing Co., Denver, Col., 1910. Pp. 166, 32 pls.

This book, in the author's words, is written "for investors who have or intend to put some money into mining ventures, and who want to know what can be done with it, and also as a sort of review of their own work for the man who is now engaged in some branch of this wonderful industry." It begins with a description of prospecting and prospecting outfits, tells something of the character of the regions in which prospecting is now being carried on in the United States and in northern and western Canada, and then describes ore deposits in a popular way.

A chapter is devoted to the location of claims and to the application of the law of the apex. Mining is then described from the beginning of prospecting to milling and smelting of the ores.

The last chapter is devoted to "Philosophy and Poetry of Mining," and is apparently written by one who loves his work and the out-of-door life into which it takes him.

The book is a good one for those for whom it is intended, but its geology and style will not bear close inspection. FRANK L. HESS.

The Occurrence and Origin of the Brown Iron Ores of Spring Valley, Wisconsin. By R. C. ALLEN. Eleventh Report of the Michigan Academy of Science.

The brown iron ores of Spring Valley, Pierce County, Wis., lie in an area thinly veneered with Illinoisan drift, near the northern margin of the Wisconsin driftless area.

Two deposits, known as the Gilman and Cady, respectively, are mined by the Spring Valley Iron and Ore Company.

The ores consist mainly of nodular and concretionary brown hydrated iron oxide mixed irregularly with ocherous clay, sand and chert fragments and nodular concretions of sand and clay. The iron content varies from about 40–59 per cent., the phosphorus from .06–.14 per cent.

The ores rest on an irregular, eroded surface of the Lower Magnesian limestone which constitutes the upper slopes of hills overlooking stream valleys cut into the Potsdam sandstone. They show very little evidence of bedding. Many small bodies of iron ore having similar geologic and topographic relations are found within the driftless area of Wisconsin and Iowa.

Allen believes that the ores were deposited in the stream valleys of a nearly plane erosion surface; that the shallowness of the ground water level peculiar to such a surface coupled with a blanket of vegetation stimulated the solution of iron and retarded its deposition until carried by ground water to the oxygenated waters of sluggish streams, where it was precipitated; and that a later uplift has caused the streams to incise their old valleys and carry away the ore, leaving only isolated patches overlooking the stream valleys of a new erosion cycle.

EDWARD STEIDTMANN.

Notes Accompanying Lectures on Geology Applied to Mining. A Course Given at the Michigan College of Mines. By EUGENE T. HANCOCK. Pp. vii + 210, 16 figs.

This is a reprint of lectures to students of economic geology in the Michigan College of Mines. "The aim on the part of the author has been to state briefly the main facts bearing upon the structural geology and mode of occurrence of the ores in most of the large mining camps of the United States." The book, mainly a series of abstracts of important reports issued by official surveys, is well done and is a convenient compend.

The first chapter describes briefly the earth's crust. This is followed by discussions of "Views Regarding Ore Deposition" and the "Chemistry of Ore Deposition." Then come descriptions of the most important deposits of iron ore, copper, lead and zinc, silver-lead, gold and silver and coal, oil and gas. At the end of each chapter is a short list of references to the papers abstracted. It is notable that in the chapter on iron ores no reference is made to the southern deposits of hematite and limonite, nor to the magnetite deposits of New York and New Jersey.

The book is printed privately for the use of the mining college students, but a limited number of copies may be obtained by the general public from the Supply Department of the Michigan College of Mines, Houghton, Mich., at the price of one dollar each. W. S. BAYLEY.

SCIENTIFIC NOTES AND NEWS[1]

BAILEY WILLIS has gone to Brazil for the Smithsonian Institution to study geologic conditions in connection with archeological investigations by Dr. A. Hrdlicka. Mr. Willis was to present the subject of the one-millionth map of the world at the congress at Buenos Ayres, and in August will attend the Eleventh International Geologic Congress at Stockholm. He expects to return to Washington late in October.

RALPH ARNOLD, of Los Angeles, made a business trip to Washington, New York and Boston the latter part of May.

THE FOLLOWING members of the U. S. Geological Survey have been appointed by the Secretary of the Interior to represent the survey at the Eleventh International Geologic Congress in Stockholm: Messrs. G. O. Smith, C. W. Hayes, Whitman Cross, S. F. Emmons, G. F. Becker, Bailey Willis and Waldemar Lindgren.

AN AMENDMENT to the Sundry Civil Bill providing for a seismological laboratory under the Smithsonian Institution, with an appropriation of $20,000 has been introduced by Senator Penrose.

E. F. LINES, of the U. S. Geological Survey, who has been working in Illinois for several years, has resigned from government work.

F. B. LANEY has been transferred from the National Museum to the U. S. Geological Survey and will assist W. H. Emmons in a survey of the Ducktown, Tenn., copper district. The party is already in the field.

FRANK A. HERALD, a graduate student in geology at Johns Hopkins University, has been appointed assistant in geology at the National Museum.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

J. H. GARDNER, of the U. S. Geological Survey, becomes a member of the Kentucky Geological Survey, July 1. He will study and report on the portland cement resources of the state.

GLACIER NATIONAL PARK has become a reality through the recent passage of a bill by Congress. This makes a game preserve of about one million acres in the Lake McDonald region in northwestern Montana. The park lies along the continental divide and includes about forty glaciers. The establishment of this park was partly due to the work of Bailey Willis, who studied the geology of a portion of the region, and to R. H. Chapman, R. H. Sargent and F. E. Matthes, topographers of the U. S. Geological Survey, who have mapped a considerable part of the present park and who appreciated its worth as a national preserve and pleasure ground.

THE DIVISION of Alaskan mineral resources of the U. S. Geological Survey will have twelve parties in Alaska during the season of 1910. Three of these parties were at work June 1 and the others were on the way to the field. J. W. Bagley and C. E. Griffin are continuing the detailed topographic survey of the Eagle River district in southeastern Alaska and Adolph Knopf will undertake to complete the geologic work in the Juneau and Berners Bay gold-bearing belt, as well as devoting some weeks to a study of the Chicago district north of Sitka.

C. G. MARTIN, assisted by F. J. Katz and Theodore Chapin, will make a detailed geologic survey of the Matanuska coal field.

THE MOST EXTENSIVE survey undertaken this year will be a topographic and geologic reconnaissance of the area lying between the Valdez-Fairbanks trail and the upper Susitna, including the southern slope of the Alaskan Range. The geologic work will be done by F. H. Moffit and B. L. Johnson, and the topographic mapping by D. C. Witherspoon and C. E. Griffin. On the north side of the Alaskan Range J. W. Bagley, topographer, and S. R. Capps, geologist, will connect with the work of Moffit and Witherspoon and cover the Nenana coal field and the Bonnifield placer district.

A. G. MADDERN, geologist, and C. G. Anderson, topographer, will make a topographic and geologic reconnaissance map of the Innoko placer district, including the northern part of the Haiditarod basin.

C. E. ELLSWORTH and G. L. PARKER began their stream gaging work in the Fairbanks district in April and will continue it through the summer in the Fairbanks, Circle and Fortymile districts.

THERE WILL be one geologic party north of the Arctic Circle. P. S. Smith and H. M. Eakin will go northward from the bend of the Koyukuk to the Kobuk and thence southwestward to Candle in Seward Peninsula. The expedition is expected to procure sufficient data for a general geologic and topographic map which will be of value to prospectors, and to make an investigation of the Kobuk River placer district.

L. M. PRINDLE, who has spent several seasons in the Fairbanks and Fortymile country, will spend the summer in the office preparing a detailed report on the Fairbanks gold district.

ALFRED H. BROOKS will continue supervision of Alaskan surveys and will leave Washington about the middle of July to visit the Martin party in the Matanuska coal field, and the Knopf party in the Juneau district. Later he will go to Fairbanks and Nome.

W. J. MEAD has been promoted from instructor to assistant professor in the department of geology at the University of Wisconsin.

DAVID H. FOLSON has been appointed assistant professor of mining, and Galen H. Clevenger assistant professor of metallurgy at Stanford University.

VACANCIES on the Coal Land Classification Board of the U. S. Geological Survey made by the resignation of C. A. Fisher and G. H. Ashley have been filled by the appointment of A. R. Schultz and W. R. Calvert. Ashley is now State Geologist of Tennessee with offices in the Capitol Annex at Nashville, and Fisher is in private practice at Denver, Colo.

AN ACT to establish in the Department of the Interior a Bureau of Mines has been passed by Congress and signed by the President. The act provides that it shall be the province of said bureau to investigate mining methods, especially in relation to the safety of miners, the treatment of ores, the use of explosives and electricity, and the prevention of accidents. The investigation of structural materials and the analyzing and testing of coals, lignites and other mineral fuel substances, and the investigations as to the causes of mine accidents now carried on by the Technologic Branch of the U. S. Geological Survey will be transferred to the new bureau. The act provides that the director of the bureau shall be thoroughly equipped by technical education and experience and shall be appointed by the President, by and with the advice and consent of the Senate. The director's salary will be $6,000. This act will take effect July 1, 1910.

DURING THE MONTH of April the Land Classification Board of the Geological Survey classified one and one fourth million acres of land that had been withdrawn for examination as coal land. Nearly one million acres were restored to entry as non-coal land. On the remaining 350,000 acres classed as coal land a valuation of $22,000,000 was placed, which is three times the minimum price. It is estimated that the coal land valuation work of the fiscal year will result in the appraisement of coal lands of over $180,000,000, probably a net increase of $130,000,000 over the minimum price. During April the board restored to entry 600,000 acres withdrawn as oil land.

THE TENNESSEE LEGISLATURE, at its last session, provided for the establishment of a geological survey to begin operations the first of May. The bill provided for a State Geological commission, composed of the Governor, the State Commissioner of Agriculture, the Chief Mine Inspector, the president of the University of Tennessee, the chancellor of Vanderbilt University and the vice-chancellor of the University of the South. This commission has held several meetings, and on March 16 elected, as State Geologist, Mr. George H. Ashley, formerly of the U. S. Geological Survey, and as associate geologists, Mr. L. C. Glenn,

of Vanderbilt University, and Mr. C. H. Gordon, of the University of Tennessee.

The new survey began its work May 1, as provided by law, the survey office being established for the present in the Capitol Annex Building, Nashville. Before beginning work regularly Mr. Ashley had made provisional arrangments for a large amount of coöperative work with several of the national bureaus, so as to nearly double the money to be spent on the geology of the state.

CHARLES H. SHAMEL, author of "Mining, Mineral and Geological Law," who is engaged in the practice of law at Seattle, Wash., recently delivered the annual course of lectures on mining law to the senior law class and the mining students of the University of Washington at Seattle.

J. B. TYRRELL has been elected a fellow of the Royal Society of Canada.

R. L. BARTLETT, recent graduate of the course of mining geology at the Massachusetts Institute of Technology, has accepted a position with Frederick G. Clapp, geological engineer, Pittsburg, Pa.

FREDERICK G. CLAPP has been examining supposed natural gas properties in Missouri.

MR. L. L. HUTCHISON, assistant director of the Oklahoma Geological Survey, has sent to press a special state report on the asphalt, oil and gas deposits of Oklahoma. In part one is a general map which shows that portion of the state in which asphalt occurs and the region where it is likely to be found. It also contains a geological map of the asphalt bearing district, and one showing the exact location of nearly one hundred known deposits. Part two is devoted to oil and gas. After reviewing the history of the industry and discussing the various theories of origin and accumulation of petroleum and natural gas, Mr. Hutchison discusses the geology of the Oklahoma petroleum and natural gas fields and closes the work with a chapter devoted to the latest Oklahoma statistics and a review of past and present conditions

in the field. This section of the report is illustrated by a general map showing the present developed areas, probable territory yet undeveloped, and those parts of the state where it seems possible that oil and gas may be found and by a geological map of the oil fields and detailed maps, on a scale of one inch to the mile, which give the location of every well drilled in the various important fields prior to 1910.

PRESIDENT CHARLES R. VAN HISE, of the University of Wisconsin, will attend the International Geological Congress at Stockholm, Sweden, this summer, sailing from Quebec on July 1 for Liverpool. He may be accompanied by Professor C. K. Leith of the geological department.

CLINTON R. STAUFFER, PH.D., instructor in geology at Western Reserve University, has been appointed assistant professor of geology in the School of Mining (Queen's University), at Kingston, Ontario.

MR. J. B. TYRRELL has been elected president of the Canadian Institute.

GRADUATE STUDENTS in geology from the University of Wisconsin spent the month of May in detailed mapping of the pre-Cambrian rocks of the Menominee iron-bearing district of Michigan. Professor C. K. Leith and Mr. W. J. Mead were in charge of the party. This work constitutes a regular course in geology at the University of Wisconsin.

THE AMERICAN INSTITUTE OF MINING ENGINEERS contemplates an excursion to the Isthmus of Panama, the trip to occupy between three and four weeks. According to the latest circular the excursion will leave New York early in November. It is proposed that the members visit not only the work on the Panama Canal but also the mines and works of the Spanish-American Iron Company on the north shore of Cuba.

MR. HOLLAND BANCROFT, of the U. S. Geological Survey, is in the State of Washington making a reconnaissance of the ore deposits in the northeastern portion of the state.

THE FOLLOWING APPOINTMENTS have been made upon the instructional staff of the School of Mines of the University of Pittsburg: A. B. Ortmann, Ph.D., professor of physical geography; P. R. Raymond, Ph.D, professor of invertebrate paleontology; S. L. Goodale, A.M., E.M., assistant professor of metallurgy; G. T. Haldemann, E.M., instructor in mining; Earl Douglass, A.M., M.S., instructor in vertebrate paleontology; H. B. Heller, instructor in mining; Dr. A. B. Wallgren, lecturer on first aid to the injured; Alexander Silverman, lecturer upon glass manufacture, in charge of glass research; W. F. Fischer, E.M., assistant in petrography; N. L. Estabrook, assistant in mineralogy; J. B. Keller, assistant in assaying.

The instructional force will be added to during the coming year and particular attention will be paid to the graduate work, especially in crystallography, mineralogy, petrography, geology and mining geology. Special attention will also be given to the departments of metal mining, coal mining, inorganic geology, ferrous metallurgy and non-ferrous metallurgy.

The year has been extended to four terms of twelve, twelve, eleven and ten weeks each, so that a student can complete his course by working any three of the terms each year. He may also complete his work and graduate in three years if he takes four terms a year. A student, as heretofore, in this school can substitute a year of practical work done under the school's direction for one year of the usual class and laboratory work, and in this way graduate in three years.

Some thirty-five thousand dollars worth of material has been added to the equipment during the last year.